A

RUDIMENTARY TREATISE

ON

MASONRY AND STONECUTTING.

PLATES ~~ONLY.~~ & Text

~~REFERRED TO IN THE SEPARATE TEXT.~~

CONTAINING FIFTY-ONE DIAGRAMS IN EIGHT PLATES ILLUSTRATING THE TEXT.

AND

FOUR PLATES OF SPECIMENS OF GOTHIC MASONRY.

BEING

PLATE IX., ELEVATION OF THE PULPIT, ST. MARIE'S ABBEY, BEAULIEU.

PLATE X., FOLIAGE ON ST. MARIE'S ABBEY, BEAULIEU.

PLATE XI., ALMONRY OF THE CHURCH OF ST. JOHN THE BAPTIST, WILTSHIRE.

PLATE XII., CHANCEL-WINDOW AND PARAPET OF SACRISTY, OF THE CHURCH OF ST. JOHN THE BAPTIST, WILTSHIRE.

BY

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EIGHT PLATES REFERRED TO BY THE TEXT.

PLATES REFERRED TO BY THE TEXT.

And an addition of Four Plates as described in Title.

INTRODUCTION.

I. This little work has been written in continuation the articles on Masonry, contained in a previous lume* of the Rudimentary Treatises. The reader ill there find an outline of the principles of equi-orium of retaining walls and arches, and a sketch of e operations of the mason, with descriptions of the ols and implements used in stone-cutting. These bjects, therefore, have not been touched upon in the llowing pages, which are devoted more particularly to e scientific operations of stone-cutting, and to the ex-lanation of the methods by which the mason obtains, om the designs of the architect, the exact shape of ch stone in a building, so that when set in its place shall exactly fit the adjacent stones, without previous ference to them.

II. The necessity for geometrical projection, in order construct the moulds and templates by which the ason is guided in his work, must always have existed om a very early period; indeed, it would be impossible o erect a stone building of any architectural preten-ions, without first arranging the joints of the masonry n a large drawing, and making full-sized projections of ome portions, such as the profiles of the mouldings.

III. It would be interesting to trace the history of lescriptive geometry in its application to masonic pro-ection; to examine how far the geometrical rules in

* Rudiments of the Art of Building.

current use amongst masons at different periods, ar out of the necessities, so to speak, of the architectu of the time when they were practised, and to ascerta what influence they, in their turn, exercised on the ch racter of succeeding styles. Thus, the exquisite profil of the Greek mouldings are true conic sections, t properties of which were well understood by the Greel whilst the corresponding members in Roman buildin are tame and spiritless, and composed of circular curv only. Again, whilst the later works of the Roman a betray a total want of rule and system, the architectu of the middle ages exhibits a very perfect and compl geometrical system of construction, arising natural out of, and yet quite distinct from, that of the classic architecture of earlier times, and equally removed fro that of the Italian revival of classic architecture, whi sprang up at the commencement of the fifteenth ce tury, and which, in the course of the sixteenth, sprea so extensively over Europe, as completely to obliterat so to speak, all traces of the rules of the mediæv architects.

IV. The history of the geometrical methods pra tised at different periods is not, however, merely matter of antiquarian interest, but is also an essenti branch of knowledge, in connection with the art stone-cutting. The character of all genuine archite ture, no matter of what age or country, is so depende on its mechanical structure, that we cannot successful imitate the style of any period, without thoroughly u derstanding the principles of construction which pr vailed at that time. This is especially the case wi Gothic masonry, which cannot be properly execute without a thorough appreciation of the peculiar ch racteristics of mediæval architecture, and of the e sential differences which exist between the methods the Gothic masons and those of our own day, whic are almost exclusively derived from the practice of t Italian school of architecture.

V. In former times the mason had probably litt

neral acquaintance with the principles of projection. ving no occasion for any rules, besides those re- ired by the architecture of his own time, he worked them without departing from the beaten track, ex- pt when some startling architectural novelty rendered modification of them absolutely necessary. But in e present day the case is quite different. We copy e architecture of all nations and all times; we intro- ce in our designs every variety of curves;* and we ecute our works in every conceivable material, from anite to gutta-percha.

VI. In this absence of any settled principles of de- gn or construction, the mason can no longer work om traditional rules, or confine himself to one parti- lar style of architecture, and it becomes necessary r him to master the principles of his art, that he ay be able to invent for each problem that may come efore him the solution best adapted to the character the work in hand.

VII. In selecting and arranging the materials for is little volume, the object aimed at throughout has een, therefore, to lay down general principles rather an to multiply examples, and will be found to differ om most works on stone-cutting, in the omission of any problems usually inserted, which are simply so any exercises on the cone, the cylinder, and the phere, and have reference only to the round forms of e Italian school, whilst we have written at some ngth on the subject of ribbed vaulting, the principles f which have not been explained, except in compara-

* The nature of the curves made use of in architectural design has a ery marked influence on the character of the work. The curves used by e Greeks were principally conic sections, which appear to have been nknown to the Romans. In the genuine specimens of the pointed style, rcular curves only, or curves made up of circular arcs of different radii, re employed, although the profiles of the diagonal ribs, in some examples f vaulting, present curves very similar to the ellipse, being struck from ree centres. In Italian architecture, elliptical curves, formed by the itersection of cylindrical surfaces, are of constant occurrence. The use f spiral curves as lines of construction, and not merely of decoration, is uite modern, and dates from the introduction of the oblique arch.

tively expensive works of a class not usually to be fou on the book-shelves of the mason.

VIII. The work is divided into three sections, follows:—

Section I.—*On the Construction of Vaults and Arches.*

The problems which present the greatest difficulti in masonry are those relating to vaulting, the perfe execution of which, from the knowledge it requires projection and of the nature of the lines produced b the intersections of curved surfaces, has always bee the severest test to which the skill of the mason ca be exposed. We have, therefore, in the first sectio briefly sketched the history of stone-cutting in co nection with this class of problems, for the purpose explaining the essential characteristics of the two grea classes of vaults, viz. the rib and pannel vault of medi æval architecture, and the solid vault of jointed ma sonry, which belong to the Roman and Italian style Several pages also have been devoted to the explana tion of the principles of skew masonry, and of th different methods of constructing oblique arches, th have been advocated by different writers.

Section II.—*On Projection.*

IX. The drawings of the architect are usually mad on a rectangular drawing-board, the horizontal an vertical lines being drawn with a T square. In th working drawings of the mason the largeness of th scale renders it impossible to make use of such aid and a considerable amount of care and system is r quired to produce a large drawing which shall be trul correct.

Again, in the designs of the architect minute acc racy is comparatively of minor importance if the draw ings are properly figured, as the mason should be guide by the written dimensions, and not by the actual siz of the different parts of the drawing. But the workin

wings of the mason exhibit the actual sizes of the
nes, any inaccuracy in the drawings materially affect-
the soundness of the work.

Ve have, therefore, in the second section given a
hints on the management of large drawings, which
y be useful to those who have not learnt, by painful
perience, the necessity of minute accuracy.

The subjects treated of in this section are arranged
follows:—

Working Drawings.—Materials; instruments; scales;
uring; copying; platform-work.

Linear Drawing.—Straight lines; protraction of
gles; measurement of right-angled triangles; pro-
ems relating to circular curves; modes of drawing
e ellipse.

Principles of Projection.—Surfaces; solids; problems
ating to the projection and development of the cone,
linder, and sphere; spiral lines; intersections of
rved surfaces.

Section III.—*On Practical Stone-Cutting.*

X. There is a class of problems connected with rail-
ay masonry that has as yet been very little studied by
orking masons; we refer to those required for working
e wing-walls of bridges. The construction of curved
ing-walls, and the nature of the twist of the coping
eds, have been explained at greater length than the
mits of this little work would at first seem to warrant.
But our reason for this has been, that the same rules
pply, with trifling modifications, to all constructions
uilt in horizontal courses with conical beds (as for ex-
mple, to take two instances apparently most dissimilar,
hemispherical dome and the spandril solid of a fan
ault); and therefore the system of lines here laid
own may be considered, to use the words of Professor
Villis, "as a general formula which includes many
particular instances."*

* Willis "On the Construction of the Vaults of the Middle Ages:"
'ransactions of the Royal Institute of British Architects, Vol. I. Pt. 2.

The subjects treated of in the third section are follows:—

Part I.—General Principles of Stone-Cuttin

Formation of Surfaces.—Plane, curved, and windi surfaces.

Solid Angles.—Nature of solid angles; problems r lative to the trihedral.

Surfaces of Operation.

Part II.—Application of Principles to parti cular Constructions.

Battering Walls on Curved Plans.

Domes.

Arches.—Arches on rectangular plans, circular a elliptical; oblique arches.

Groined Vaulting.—Roman vaulting; ribbed vaul ing.

XI. In concluding these introductory remarks, may be necessary to add that the reader is presumed have a knowledge of plane and solid geometry, as w as of the elements of plane trigonometry.

As not only acquaintance, but familiarity with the subjects is indispensable to the proper understanding the more difficult problems in stone-cutting, especial those connected with skew masonry, no purpose wou have been answered by inserting in this volume a pr paratory treatise on geometry, which must have n cessarily been too brief to be of any real value; a the introduction of which would have excluded mu matter bearing more immediately on the subject of t work.

E. Dobson.

RUDIMENTS

OF THE

ART OF MASONRY.

SECTION I.

ON THE CONSTRUCTION OF VAULTS AND ARCHES.

VAULTING.

1. THE construction of plain cylindrical vaults in which the faces, beds, and joints of all the stones are plane surfaces, either perpendicular to, or radiating from, the axis of the cylinder, presents no particular difficulties, the only lines that have to be made use of being straight lines and circular curves; and accordingly we find that, from the earliest times, the construction of common cylindrical vaults, both in brick and stone, appears to have been well understood, arched vaults being found amongst the ruins of Nineveh,* whilst arches of brick and stone are still remaining at Thebes† and Saqquara, in evidence of the knowledge of the arch possessed by the ancient Egyptians. Whether the Greeks were acquainted with the principle of the arch, is still a disputed

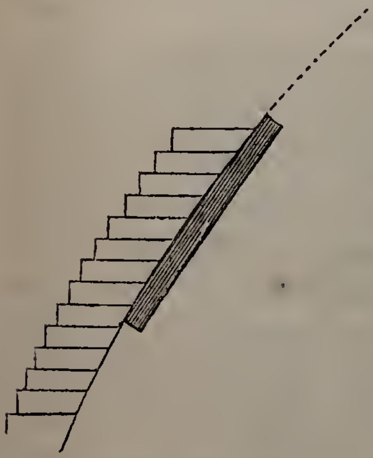
* *Vide* Layard's "Nineveh."

† *Vide* Wilkinson's "Manners and Customs of the Ancient Egyptians."

point. Further than this the ancients do not appe to have advanced, and we have no evidence to sho that the now familiar problem of finding the profile a groin from the square sections of a vault by means ordinates, was at all known before the eleventh, or th it was generally practised before the fifteenth centu of the Christian era.

2. The very curious dome-shaped building at My cenæ, in Greece, known by the name of the "Treasu of Atreus," affords valuable evidence as to the amount knowledge possessed by its builders of the principl of dome vaulting. The inside of the building forms pointed dome of 48 ft. diameter, and of about the sam height, the section presenting two intersecting arcs about 70 ft. radius. The difficulties which attend th working of such a vault wit radiating beds have bee here evaded by making th beds horizontal throughou the top being formed of a fla stone. Nothing more, there fore, was necessary than to cu the soffit of each course to th required angle with its bed which could readily be don by means of a templet cut t the radius of the vault, a shown in fig. 1.

Fig. 1.



3. Although the principle of the arch was known a a very early period, the arch was never employed t any great extent before the Roman age. Its form di not harmonize with the severe horizontal features c the columnar architecture of Egypt and Greece, whils its employment was not a principle of construction a

ıongst the Romans, who built in a great measure th brick, and who probably had not the means of ecuting the flat massive stone roofs with which the ;yptians covered their halls and porticoes.

4. We must, however, guard against assuming, from e general absence of the arch in Grecian architecture, at the Greek architects were unacquainted with geoetrical methods of describing elliptical or any other rves.

The singular facts respecting the curved lines of the reek temples, which have been recently placed beyond e possibility of dispute by the careful measurements Mr. F. C. Penrose,* who devoted five months to e investigation of the curves of the Parthenon alone, ıow that they must have possessed very perfect ethods of setting out and executing their work, the ərfection of which it would be impossible to excel, ıd which it would be difficult at the present day to ıual. The leading facts to which we refer are briefly ıese; that the lines of the pavements, architraves, and ərnices are not horizontal, but curved; and that the ıtasis or vertical curvature of the columns, and the ·ofiles of the mouldings are true conic sections; being ther hyperbolic or parabolic curves. No traces of a nowledge of conic sections are to be found in the ·chitecture of the Romans, whose works are often ‹ecuted in a coarse and slovenly manner, and whose ıouldings are formed of circular curves only, instead ŕ presenting the delicate curves we find in the works ; the Greeks.

5. With the introduction of the arch by the Romans ; a leading principle of composition, commences a new

* "Two Letters from Athens, by F. C. Penrose, Esq." Published r the Society of Dilettanti.

era in the history of construction. The arches of Thebe and Nineveh were of small dimensions and of little im portance, but the vaults and domes of the Romans wer of such spans as would at the present day, with all ou mechanical means and scientific knowledge, be consi dered bold undertakings. Thus, the dome of the Pan theon, at Rome, is a hemisphere 139 ft. in diamete and the groined vaults of the building known by th name of the Temple of Peace were upwards of 70 f span. The works of the Romans exhibit great prac tical knowledge of the equilibrium of arches; and i the building just mentioned, and in the vaulted roofs o the large halls attached to the public baths, we find th arrangement of the groined vault supported by massiv arched buttresses, the type of the groined vaults, an flying buttresses of the middle ages.

6. There is, however, no evidence in the works o the Romans of any knowledge of the scientific opera tions of stone-cutting. Their domes and cupolas coul have been constructed with a very simple system o centering, as each course, when completed, becam self-supporting, whilst the construction of their groine vaults exhibits an unscientific evasion of constructiv difficulties, quite in keeping with the general inatten tion to minute details, which is one of the characterist features of Roman work.

7. If two vaults of the same height at the crown but of different spans, are to be made to intersect eac other, some arrangement is required, in order that th groins, or intersections of the vaulting surfaces, sha lie in vertical planes. In our time, the usual pla adopted is, first to design the curve of the princip vault, and to make the form of the lesser vault depen dent upon it, the curve being found from that of th

rincipal vault by means of ordinates, as shown in fig. 2, ate 1, where the square section of the larger vault is semicircle, and that of the smaller one a semi-ellipse. his method is, of course, applicable to all cases of itersecting vaults, whatever their curvature may be.

8. This method of finding the profile of a groin by rdinates, from the square section of the principal vault, oes not appear to have been known, or at all events ractised by the Romans, and their method of getting ver the difficulty was to stilt the springing of the esser vault, making the sections of both vaults semi-ircles of different radii. The consequence of this ar-angement is, that the vaulting surfaces do not intersect n vertical planes, and the groin forms a waving line, s shown in fig. 3, plate 1. The vaulted roofs of the halls f the Baths of Diocletian and Caracalla are examples f this contrivance, which was also made use of in our wn country before the twelfth century, when plain cross vaulting began to be superseded by rib and pannel vaulting, which, in its turn, fell into disuse on the re-vival of the classic style of architecture in the fifteenth and sixteenth centuries. In Germany another contri-vance appears to have been adopted, which we shall pre-sently describe.

9. So early as the time of Constantine, the art of constructing vaults seems to have been on the decline, and the roofs of the early Christian churches in Italy were of wood, with the exception of the eastern semi-circular apse, which was always covered with a plain semi-dome.

10. In the sixth century was erected the celebrated dome of St. Sophia, at Constantinople. This is a flat dome, 115 ft. in diameter. Soon afterwards was built the church of St. Vitalis, at Ravenna, which has a

hemispherical dome, 54 ft. in diameter. This latte dome is the first example of the re-introduction c dome-vaulting into Italy, after the decline of the Rc man art. These two celebrated domes were constructe of earthenware and pumice-stone, and presented, con sequently, no difficulties in stone-cutting.

After the erection of St. Vitalis, plain groined vault of small span became very common, although the nav roofs of the Italian churches continued to be constructe of wood, with flat ceilings, until the 13th century, whe the pointed style was first introduced into Italy. Thes vaults are usually divided into compartments, by fla bands, an arrangement which continued to be practise long after the introduction of ribbed vaulting.

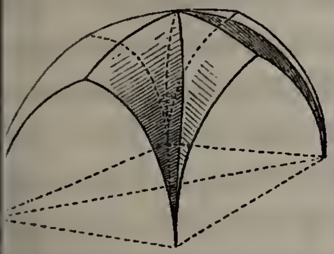
11. The crowns of the Roman vaults were mad level throughout, and we find this arrangement to hav prevailed in our own country until the introduction o the more complex forms which we shall presently describe. But on the Continent a different system seems to have prevailed, the nature of which we shall endeavour to explain.

12. In the construction of a plain waggon vault with cross vaults, the easiest way of forming the centering is to make a complete centering for the main vault, and on it to place the centres for the cross vaults. This dispenses with the necessity for finding the curves of the groins, and the cross vaults may be made of any shape, without regard to their intersection with the main vault, as the groins, to use a familiar phrase, will "*find themselves.*" The irregularities of the groin lines of the Roman vaults would seem to indicate that they were built in this way. A centering of this kind is, however, very defective, being weak at the most important parts, namely under the groins.

The obvious remedy is to construct the centering :h diagonal ribs. But here comes the important estion—how is the profile of these ribs to be obned?

13. It is very evident that, for the vaulting surfaces be cylindrical, the rib must be of a flatter curve an the square section of the vault. If the latter be semicircle, the former will be a semi-ellipse, and if e form of the vault be pointed, that of the rib will be pointed arch formed of two elliptical curves. We ve already said, that the method of obtaining the ofile of a groin by ordinates does not appear to have en formerly known, and in the early German vaults e difficulty is got over in a very simple and satisfacry manner, by abandoning the principle of keeping the surfaces cylindrical and making the groins portions of circular curves.* The structure of these early vaults is highly domical, the curvature of the groins being such as to throw their intersection much higher than the summit of the transerse and longitudinal ribs, by which each compartment f the vault was bounded. (See fig. 4.)

Fig. 4.



14. This expedient does away also with all difficulty rising from the unequal span of two intersecting aults, and introduced the important principle of deigning the profiles of the groins, and leaving the form f the vaulting surface to adapt itself to them, whilst, n the Roman and Italian styles, the form of the vault-

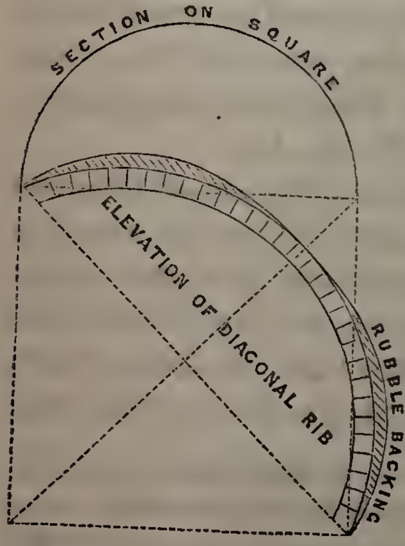
* Probably in many cases a semicircle, to judge from the domed appearance of the vaulting in most of the early German churches; but, in he absence of careful measurements, it is impossible to say what rule was ollowed in this respect.

ing surface is first settled, and the profile of the gro[in] follows from it as a matter of necessity. The domic[al] form of vault was extensively used abroad, especially [in] Italy; but in England it is not common, and our ear[ly] vaults were constructed on the principle of keeping th[e] crowns level.

15. The early Norman vaults of our own countr[y] are plain rubble vaults, similar to those of the Roman[s] and exhibiting the same expedients of stilted springing[s] and waving groins. But at an early period the system of solid vaults, with continuous vaulting surfaces, bega[n] to be superseded by a less massive mode of construc-tion, appropriately called, by Professor Willis, "Ri[b] and pannel work." This style of vault consists of [a] framework of light stone ribs, filled in with pannels either built in courses of small stones, or formed of thi[n] slabs, cut to fit the spaces between the ribs.

16. The introduction of diagonal ribs rendered i[t] necessary to make use of some method of obtaining [a] face-mould for the groins[;] but this was not done by th[e] methods described above[.] The common system appear[s] to have been, either to mak[e] the diagonal ribs semicircu-lar, and to stilt the springing[s] of the transverse and longi-tudinal ribs; or, to make the diagonal ribs segmental. I[n] either case, the intersections of the vaulting surfaces rose considerably above the dia-gonal ribs at the haunches[,] and, to meet this difficulty[,] the backs of these ribs were packed up to meet the

Fig. 5.



ılting, which thus rests on thin walls of rubble, in-
ad of on the walls themselves. This is shown in fig. 5.
ı example of the first-named expedient is to be seen
a vaulted apartment in the castle at Newcastle-upon-
ne. The aisles of the nave of Peterborough cathe-
ıl are examples of the second. Sometimes we find
ɜ diagonal ribs semicircular, and the transverse ribs
inted, arches. This construction may be seen in
me vaults on the west side of the south transept of
ɜterborough cathedral.

17. But although the above described arrangements
ɜre those in common use, there are instances of plain
ults without diagonal ribs, which present the modern
rangement of making the profile of the groin de-
ɜndent on the form of the principal vault.

The ruins of some old buildings in Southwark, for-
erly belonging to the Prior of Lewes, in Sussex,
ɔntained vaults of this description. One of them is
ɜscribed in the "Archæologia," Vol. XXIII., and also
ı Brayley's "Graphic Illustrator," from which the ac-
ɔmpanying illustration, fig. 6, is copied. The length

Fig. 6.

of the vault here shown was 40 ft. 3 in., the widt 16 ft. 6 in., and the height 14 ft. 3 in. The mai vault was semicylindrical, and was intersected by fo cross vaults of elliptical section. The ribs were stone; the vaultings of chalk. The arch over th entrance doorway of the apartment was also of a elliptical form. The building is supposed to have bee erected in the twelfth century, but we have no precis information on the subject.

18. It might naturally be expected that the nex step in ribbed vaulting, beyond the rude expedient o backing up the diagonal ribs, would have been to ac commodate the curvature of the *diagonal ribs* to that o the vaulting surfaces; but, instead of this, we find new principle of design introduced, which was to adjust the *vaulting surfaces* to the curvature of the ribs to which they were made perfectly subordinate, each rib being struck from one or more centres, and designed without any immediate reference to the curvature of the adjoining ones.

19. In the Roman system of vaulting, the vaulting surface is everywhere level in a direction parallel to the axis of the vault; and any horizontal section of the spandril of a groined vault taken between the springing and the crown would be a rectangle. But in the Gothic ribbed vault this is not the case, for the plan thus formed would present as many angles as ribs, and admits of great variety according to the curvature of the latter. Thus in fig. 7*, the plan of the spandril at A, by a trifling alteration in the curves of the ribs, might be made at pleasure to form any of the figures shown at *a*, *b*, *c*, and *d*.

20. The varieties of ribbed vaulting practised during the Middle Ages may be divided into three classes.

1st. The Plain Ribbed Vault.

2nd. The Lierne Vault; in which numerous *liernes* short ribs are introduced, disposed in connection with e principal ones, so as to form star-shaped figures und the imposts, as well as a regular pattern at the ntre of each compartment.

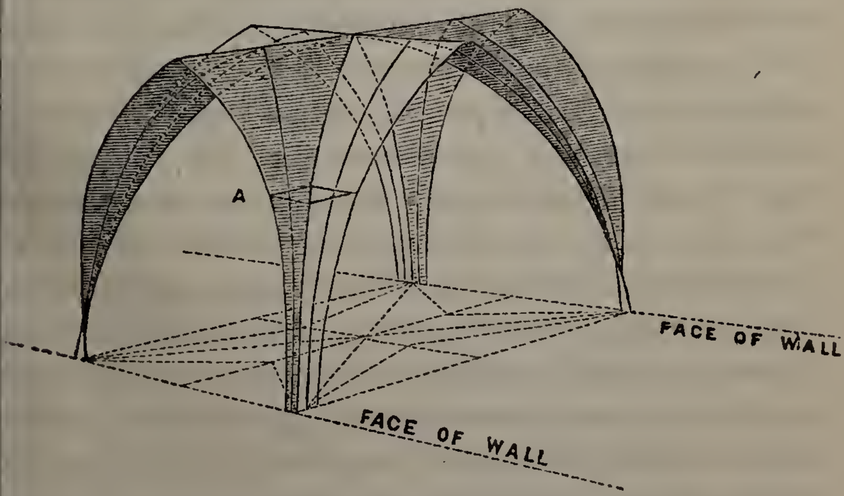
3rd. The Fan Vault; in which all the main ribs ve the same curvature, and form equal angles with ch other at their springing.

We do not propose to enter upon any description of e architectural design of these vaults or of their decotive features, but it is necessary to say a few words ı their mechanical construction.

21. *Plain Ribbed Vaulting.*—A simple example of is is shown in fig. 7. These vaults are sometimes

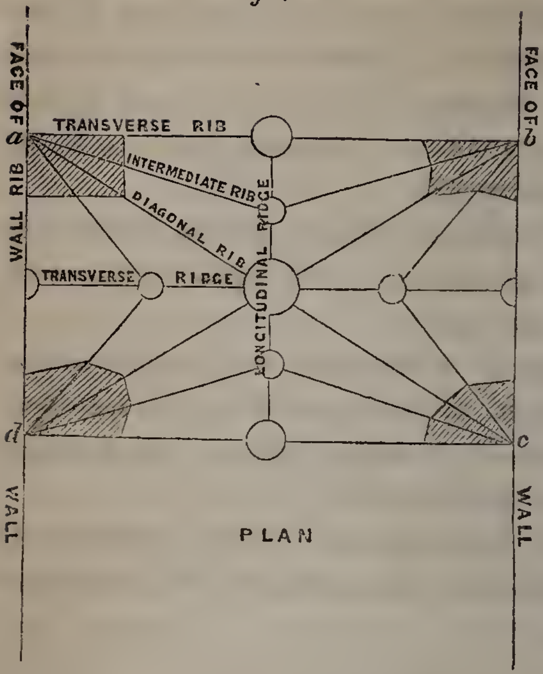
Fig. 7.

PERSPECTIVE VIEW.



ɔund without ridge ribs, and sometimes with them, ıe latter case being of the most frequent occurrence. ometimes there are only diagonal, transverse, and

Fig. 7.*

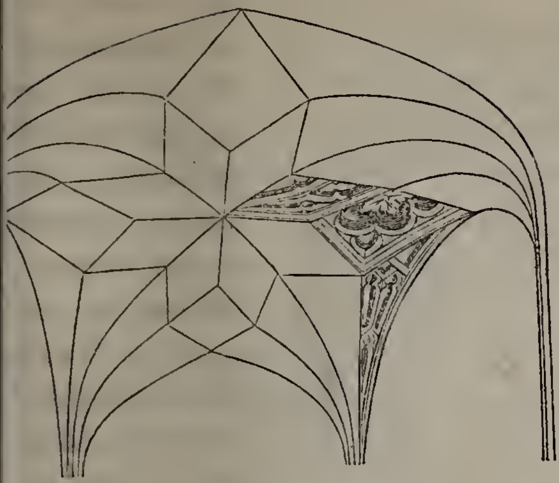


longitudinal ribs; in other examples we find intermediate ribs introduced between the diagonal and transverse, and longitudinal ones. The ridges are generally horizontal, but not universally so.

Plain ribbed vaults were much used in France, and in the Italian churches, and were often decorated with painting.

22. *Lierne Vaulting.*—In this class of vaults the ribs are very numerous, and the liernes divide the spaces into compartments, which are filled with tracery. In the previous class of vaults, each rib marked a groin; that is, a change in the direction of the vaulting surface; but in these many of the ribs are merely *surface* ribs; that is, they lie in a vaulting surface, whose form is determined independently of them, and regulates their curvature. Many vaults of this class, although apparently of very intricate design, are in reality vaults of simple forms decorated with a profusion of surface ribs. A good example of this kind of vaulting, from the cloisters of St. Stephen's, Westminster, is given in fig. 8. The construction of vaults of this class requires a very thorough knowledge of projection, as the pattern of the vault must be first laid down upon the plan

Fig. 8.

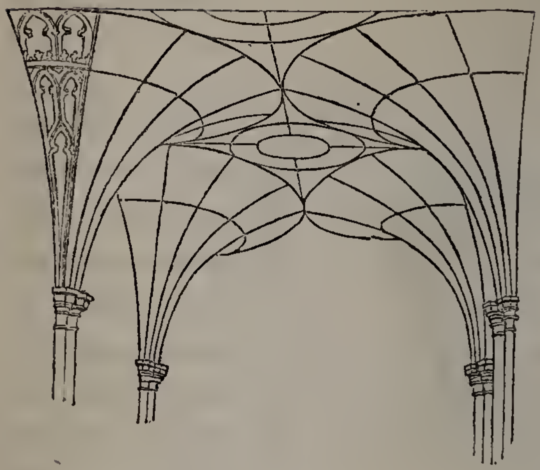


in which the curved lines of the ribs will of course become so foreshortened, that it gives very little idea of the perspective effect of the work in execution. The designers of these vaults must erefore have possessed the power of conceiving in eir minds the effect they wished to produce, and have iderstood how to distort the plans accordingly.

It is not probable that this was done by any regular :ometrical methods; it was more probably the result experience and observation on the effect of existing iults. This is confirmed by the very unequal charac-r of remaining examples; in some, the meaning of the :sign is hardly to be made out from the plans, whilst . others the plans exhibit symmetrical arrangements, hich are lost in execution from the distortion of the nes.

23. *Fan Vaulting.*—In the fan vault, the main ribs have .l the same curvature, and form equal angles with each ther: the liernes also are horizontal, each set forming quadrant, where the vault is divided into rectangular ompartments, as at King's College Chapel, Cambridge; nd where this is not the case, a semicircle, as in the xample given in fig. 9, which is from the cloisters of t. Stephen's, Westminster. Lierne and fan vaults were ften used in the same building, as in the examples

Fig. 9.

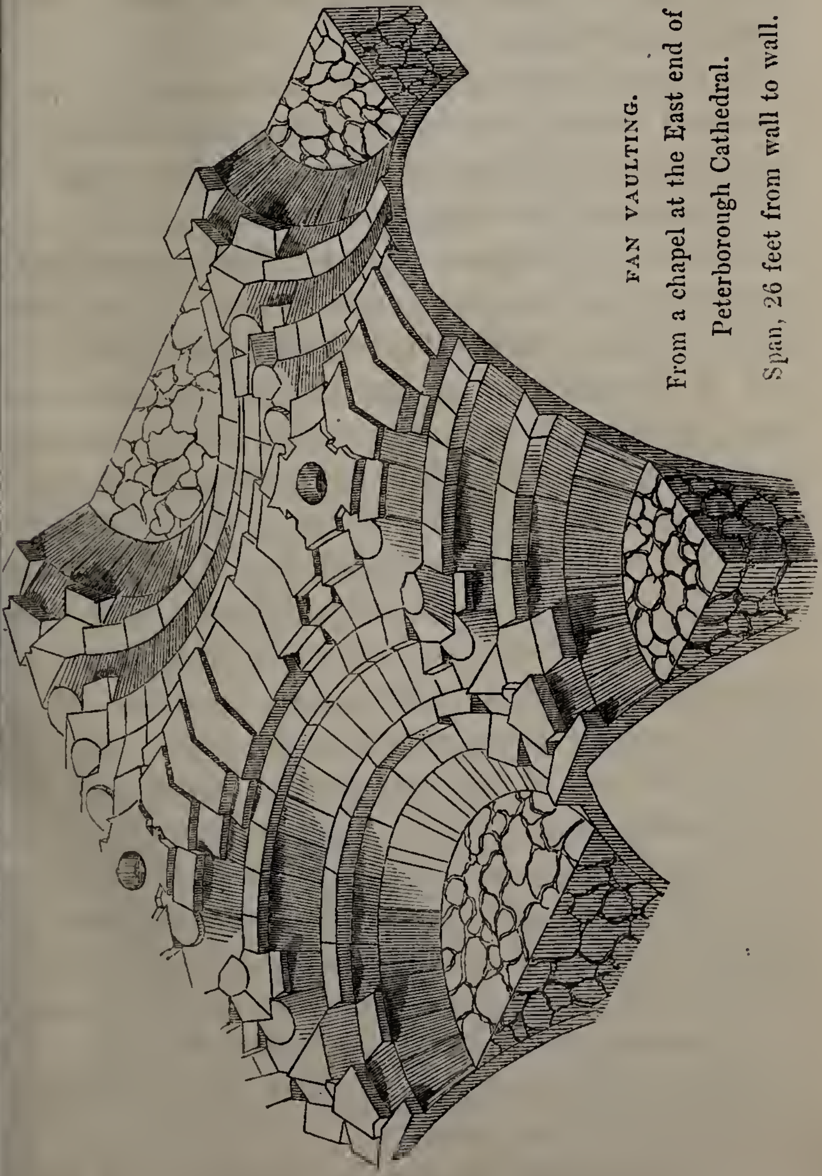


here given from the cloisters of St. Stephen's, of which the *walks* are covered with fan vaulting, whilst the compartments at the angles are vaulted as shown in fig. 8. But with the invention of the fan vault came also a change in the system of construction, which was also applied to the latter lierne vaults when executed in connection with fan vaults.

24. The early lierne vaults display the same system of construction as the plain ribbed vaults, viz. a skeleton of ribs filled in with thin pannels. In proportion to the complex character of the designs the ribs became more numerous and the pannels smaller, until it was found more convenient to execute the whole vault of jointed masonry, the pannels being sunk in the soffits of the stones instead of being separate stones resting on the ribs. This new system was first introduced on the crowns of the fan vaults, where, from the ramifications of the tracery, the ribs were most crowded, and was soon extended to the construction of the entire vault, although in many instances we find the lower portions, which consist of plain ribs only, to be of ordinary rib and pannel work, whilst the more decorated portions are of jointed masonry. The vaulted roof of King's College Chapel, Cambridge, is an example of the latter mode of construction: that of King Henry the Seventh's

apel at Westminster, on the other hand, is built en-
ɪly of jointed masonry.

25. The art of stone-cutting appears to have reached highest development at the commencement of the teenth century; the works of this date exhibiting a



FAN VAULTING.
From a chapel at the East end of Peterborough Cathedral.
Span, 26 feet from wall to wall.

perfect mastery of the subject. Some idea of the complex character of the masonry of a fan vault may b obtained from an inspection of fig. 10, which is reduced by permission of Professor Willis, from one of th plates accompanying his valuable paper on the "Construction of the Vaults of the Middle Ages," in th first volume of the Transactions of the Royal Institut of British Architects.

26. Ribbed vaulting was introduced into Italy in th thirteenth century, the church of St. Andrea di Vercelli in Piedmont, of which the first stone was laid A.D 1219, being the first example of its use.

Although the pointed style attained to considerabl perfection in Italy, the round forms of the Roman style of vaulting were never entirely superseded. Indeed, the greater part of the Italian ribbed vaults are merely plain vaults with ribs on the groins, and are, in many examples, divided into compartments, by the flat band of the earlier round vaultings, which in the genuine Gothic became a moulded rib. There are many peculiarities in the Italian ribbed vaults, which mark their distinct character, and show that the pointed style never became perfectly naturalized in Italy. We do not find in them either ridge ribs or liernes, and even the vaulted roof of the cathedral of Milan is a plain ribbed vault, ornamented with *painted* tracery.

27. In Germany and the Netherlands we find lierne vaults of very complex character, some of them exhibiting designs which would seem to have been invented solely for the purpose of showing the skill of the mason in overcoming the difficulty of their execution. The use of fan vaulting appears to have been confined exclusively to our own country.

28. The principal authorities referred to in writing

brief sketch of the history of ribbed vaulting are— paper by Professor Willis before referred to; the k by the same author, "Remarks on the Architec- : of the Middle Ages, especially of Italy; "Archi- ural Notes on German Churches," by the Rev. Dr. ewell;" and Gally Knight's "Ecclesiastical Archi- ure of Italy." These valuable works cannot be too l studied by those who wish to obtain a clear insight the principles of ribbed vaulting, as practised in own and other countries.

9. The abandonment of the principles of the ribbed lt, and the revival of solid vaulting with elliptical ins, may be dated from the commencement of the h century. In 1417 Brunelleschi brought forward plan for the erection of the celebrated cupola over crossing* of the Duomo, at Florence, which was rly completed at his death, which took place A.D. 4. This magnificent cupola, which was the first at work of the revival, is built of brick,† like most er Italian domes; it is octagonal in plan, 138 ft. in meter, and 133 ft. in height, from the springing of vault to the base of the lantern.

About the same time an Italian architect built the l existing Church of the Assumption, at Moscow, of ich the vaults are of hewn stone.

30. The Italian architects who flourished during the nainder of the 15th century, followed classic models nost exclusively; and the revival of the columnar les, and of the round forms of vaulting, gradually read northwards, although it was not until the middle

* The *crossing* is that part of a cross church at the intersection of the e and transepts.

† Lined with marbles of different colours.

of the sixteenth century that the principles of the reviv produced any decided effect on the architecture of o own country.*

31. The great masterpiece of the modern Itali style of vaulting is the dome of St. Peter's at Rom 139 ft. in diameter, built at the close of the sixteen century, from the designs and instructions left for th purpose by Michel Angelo.

This was only a few years after the completion, England, of the exquisite vaulted roofs of King's Co lege and Henry the Seventh's Chapel, before alluded t

The dome of St. Peter's exhibits an advanced know ledge of the application of stone-cutting to dome being executed of regular masonry; whilst the earli domes and cupolas were built of bricks, hollow earther ware pots, pumice stone, and similar materials. It i however, defective in design, from its form not bein suited to support the weight of the lantern, and parti failure has taken place.

32. In the year 1568, a century after the erection the cupola of the Duomo, at Florence, and during th building of St. Peter's, at Rome, Philibert De Lorme, celebrated French architect, published a work on arch tecture, which contains a complete system of lines fo stone-cutting. This is the first published book whic treats of masonic projection, all earlier writers bein silent on the subject.

In De Lorme's time, ribbed vaulting had fallen int disuse, and he speaks of Gothic vaults, and of th

* The eastern windows of the choir at Lichfield cathedral are fille with stained glass, brought from Germany, the execution of which dat about 1530. The architecture introduced in these paintings is of Italia character, with columns, entablatures, and other features of the reviva which had not then reached England.

:hods practised for the adjustment of the curvatures .he ribs, as belonging to a bygone age, considering works of the Italian school to be the only ones :thy of the name of true architecture. At the same e he acknowledges the extraordinary mechanical l displayed in their construction, which appears, in eyes, to have been their chief merit.

;3. From De Lorme's time to our own there is little :th noticing in the history of the art. His work was owed by those of other French writers, who copied constructions, and on the Continent the study of ›metrical projection has always formed a prominent nch of the education of the architect.

;4. The admirable construction of the vaulted roof* St. Paul's cathedral attests the knowledge of the hitect, and the mechanical skill of the workmen ployed in its construction. But, with the excep- n of a treatise by Halfpenny, published A.D. 1725, have no works of that date on stone-cutting, and leed possess scarcely any English publications on : subject, except those published within the last few ırs, amongst which the works of Mr. Peter Nichol- ı stand conspicuous for their completeness. Mean- ile the principles of the construction of the mediæval bed vaults seem to have been completely forgotten, l so totally misunderstood, that both Halfpenny and cholson give methods, in their works, for construct- ; Gothic vaults, with diagonal ribs projected from : transverse rib by ordinates; a system which we ve shown to be quite at variance with the genuine ıracter of ribbed vaulting.

The *dome* of St. Paul's is only a wooden covering placed round the :k cone supporting the lantern, and is merely a picturesque addition to structure, not an essential part of the construction.

OBLIQUE ARCHES.

35. We now come to a new era in the history of t arch. About twenty years ago was introduced a n system of building arches, totally unpractised before this country; we allude to the erection of oblique skew bridges built in spiral courses.

Oblique bridges seem to have been known on t Continent long before their introduction into this cou try, and Vasari mentions one built over the river M gnone, near Florence, as early as 1530*; but the a does not appear to have been generally understoo for, very recently, the Chevalier Mosca, whilst desig ing the stone bridge built by him over the Dora R paria, near Turin, considered the erection of an ol lique arch too hazardous an undertaking, and went a heavy expense in forming new approaches, in ord that the bridge should cross the river at right angles the stream.

36. In England the art of building oblique bridg arose simultaneously with the development of the rai way system. Before the introduction of railways, fe bridges were built except for carrying common road over rivers and canals, and such bridges were uniforml erected on a rectangular plan; and, in cases where th direction of the road was not at right angles to th stream to be crossed, the approaches were turned a might be necessary to effect this. The speed of th locomotive engine rendered this arrangement quite inad

* Vasari. "Vite dei Piu Eccellenti Pittori." Firenze, 1568. The editio of 1550 contains no notice of this work. The bridge in question was buil by Nicolo, surnamed Il Tribolo, on the main road to Bologna, outside th gate of San Gallo, at Florence, and seems to have excited much interes at the time of its erection. No details are given of the principles on whic it was constructed.

ible to bridges erected for carrying railways across
ing communications; and accordingly, with the
introduction of locomotives, arose the necessity for
tructing arches on oblique plans.

. Amongst the first stone skew bridges built in this
try of any size was one erected by Mr. John
ey, A.D. 1830, over the River Gaunless, near Dur-
, on the Haggar Leases Branch Railway, a mineral
joining the Stockton and Darlington Railway. The
e of this bridge is 26° 54′, the direct span 12 ft.,
the oblique span 42 ft., and it was at that time
idered a very bold undertaking.

ther skew bridges were built about the same time
he Stockton and Darlington, the Liverpool and
chester, and other railways; they soon became
non, and their construction is now well understood.

. If an arch could be built in such a manner that
nortar joints should be as strong as the voussoirs
iselves, it would signify but little in what direction
ourses are built; and the construction of an oblique
built either of brick or rubble, offers no difficulty
e cementing material can be depended upon in this
ect. But in building with common mortar, or in
ructing arches of regular masonry, in which no
ndence is placed on the adhesion of the cement, it
nes necessary to place the courses at right angles
e faces of the bridge, in order to bring the thrust of
rch in the right direction, and to keep the obtuse
is from sliding outwards.

is this which constitutes the peculiarity of the
ue arch; for the courses not being horizontal, their
iation will be constantly varying, from the springing
e it is least, to the crown, where it is greatest; and
ccurate working of this *twist*, as it is called, of the

beds, is the great practical problem to be solved in t
execution of skew masonry.

39. The ordinary method of building a skew arch, f
11, plate 2, is to make it a portion of a hollow cylind
the arch-stones being laid in parallel spiral courses, a
their beds worked in such a manner that in any secti
of the cylinder perpendicular to its axis, the lines form
by their intersection with the plane of section sh
radiate from the axis of the cylinder. In this mode
construction the soffit of each stone will be a portion
a cylindrical surface, and the twist of the beds will
uniform throughout the whole of the arch; so that
have only to settle the amount of the twist, and t
stones can then be worked with almost as great facil
as the voussoirs of an ordinary arch. The headi
joints, or those which divide the stones of each cour
are portions of spirals intersecting at right angles t
coursing joints, or those which separate the courses,
that the voussoirs are rectangular on the soffit. T
quoins, or voussoirs in the faces of the arch, are, ho
ever, exceptions to this rule, for the following reas
If a heading spiral be drawn on the centering of
arch, touching the extreme points of the imposts, it w
lie partly within, and partly beyond, the plane of t
face. The heading joints, therefore, will not be paral
to the face-line, and all the quoins will differ more
less from a rectangular form. Another peculiarity
this mode of construction is, that the joints in the fa
of the arch are not straight, but curved lines, who
chords will all radiate from a point below the axis
the cylinder, the distance increasing with the obliqu
of the bridge.

40. The merit of first explaining the construction
the oblique arch is due to Mr. Peter Nicholson; wh

328, published his "Practical Treatise on Masonry Stone-cutting," in which directions are given for king the voussoirs of a skew arch in spiral courses. remained the only work on the subject until 1836, n Mr. Charles Fox published a pamphlet "On the struction of Skew Arches," which enters into the ect very fully, and explains the mode of working beds with twisting rules. This was followed in 9 by Mr. Buck's Treatise, in which the subject is dled with great clearness and simplicity, and tri-ometrical formulæ are given for obtaining the di-sions of every part of a skew arch by calculation, ead of by geometrical constructions. In 1845, Barlow brought out a pamphlet, as a kind of el to Mr. Buck's work, containing a diagram for ining, by measurement with the scale, most of the required in the erection of oblique arches. The of this diagram greatly facilitates the practical ap-ation of Mr. Buck's formulæ. In 1839, Mr. Peter holson published his "Treatise on the Oblique h," which explains the subject very fully, though with the conciseness and precision which charac-zes Mr. Buck's work. It is, however, a very valu- treatise; and, from the number of problems intro-ed, is well suited to be put into the hands of the lent.

1. All the treatises above mentioned are written 1 one common object, viz. the construction of cylin-al skew arches in spiral courses, with beds of uni-n twist radiating from the axis of the cylinder. It carcely necessary to remark that skew arches may constructed in a variety of ways. Thus an ordinary w arch, built as above described, is a semicircle, or e portion of a circle, on the square section, and

elliptical on the face, which is an oblique section o portion of a cylinder. But it is quite possible to ma the square section elliptical; in which case the face the arch will present an elliptical curve, flatter than tl of the square section. Again, instead of radiating t bed-joints from the centre of the cylinder, they may made perpendicular to the curve of the soffit on t oblique section, as in fig. 12, plate 2, which certainly h a better appearance in the elevation of the face of tl arch. Both the last-named methods, however, introdu more complexity in the working of the stone; as tl twist of the beds will be constantly varying from tl springing to the crown, and a great number of twistir rules will be required. So, again, the irregularity in tl soffit plans of the face quoins may be done away wi by making the heading joints lie in planes parallel the face of the arch (see fig. 12, plate 2), which giv the soffit a very regular appearance, but weakens tl voussoirs by throwing them out of square; the acu angles being liable to be fractured by a very trifling se tlement.

In 1837, Mr. John Hart published a "Practic Treatise on the Construction of Oblique Arches," i which these methods are described, with many other which we need not here particularize. The peculia features of Mr. Hart's system are shown in fig. 1 plate 2, which is taken from the work just mentioned.

42. About the year 1838, Mr. A. I. Adie, the resident engineer on the Bolton and Preston Railway executed several oblique bridges on that line, the con struction of which differs in many respects from th methods above described. The construction of one o these bridges, viz. that over the Lancaster canal, i shown in fig. 13, plate 3, which is copied from the draw

s presented by Mr. Adie to the Institution of Civil gineers, to accompany a paper on these bridges read session 1839, and is here published by permission of Institution. The peculiarity in the design of this dge consists in twisting the coursing joints, so that y shall be perpendicular to all sections of the soffit, de by planes parallel to the face of the arch. The ult of this arrangement is, that the courses are not uniform width, but diverge from the springing, where y are narrowest, to the crown, where they are widest. e square section of the arch is elliptical, not circular, l the bed-joints are worked so as to be everywhere pendicular to the curve of the soffit on the oblique tion.

13. The object proposed by Mr. Adie in the arrangent here described was to bring the thrust of the arch npletely parallel to the face, which can only be omplished approximately with spiral courses of unim width. But the curved plans of the stones at the inging, and the difficulties which arise in the magement of the face joints, from the stones not being one width, form great obstacles to its general induction.

44. In the Bath viaduct on the Great Western ilway are two skew arches of peculiar construction. ese arches cross the public roads to the west of the th Station; they are four centered gothic arches, d are built with courses diverging from the springing the crown.

45. We have gone to some length in our remarks on e different methods of constructing skew arches in der to induce a careful study of the subject on the rt of the reader. In ordinary cases the cylindrical m is the best that can be adopted; but cases may

sometimes occur to which this is inapplicable, and t architect will then find it necessary to adapt the mo of construction to the necessities of the case. N specific rules can be laid down for the treatment o such cases; but the student who has thoroughly mas tered the principles of the subject will find no difficult in applying them in any instance that may occu however complicated.

SECTION II.

ON PROJECTION.

WORKING DRAWINGS.

46. As some of our readers may not be practicall acquainted with the routine usually adopted in th erection of large buildings, it may be desirable to sa a few words on the subject, that the nature of th working drawings required by the mason may be full explained.

47. On receiving the designs and instructions of th architect, the mason's first proceeding is to select a con venient spot of ground for a stone-yard as near to th site of the works as practicable, and to erect his work shops and the necessary machinery for lifting the blocks if the scale of the works be such that they cannot b conveniently moved without mechanical aid.

48. These preliminaries being arranged, the next thing is to order the stone from the quarries that have been chosen; and in order to determine the shapes and sizes of the blocks that will be required, the mason prepares from the designs of the architect a series of drawings

a large scale, on which he marks the heights of the eral courses and the arrangement of the stones in h course, numbering all the stones that require to worked to definite dimensions. He then makes a edule of the numbers and sizes of the blocks required, ich is sent to the quarry. Each stone being dis-guished by its proper number from the time it leaves quarry to its finally resting in its appointed place the building, no confusion will arise during the pro-ss of the work, care being taken to number the cks as nearly as possible in the order in which they to be set, as attention to this point saves much time l trouble in the execution of the work.

49. Whilst the blocks are being hewn at the quarry, mason is busily engaged in preparing the rules and nplets which will be required in dressing them to eir exact shape. For this purpose he lays down on arge wooden floor, or *platform*, full-size plans and ctions of the work, course by course, carefully mark-g the joints according to the working drawings pre-ously made; and from the full-size drawings the nplets and bevels are made. Each templet is num-red, to correspond with the number of the block to ich it is to be applied, so that no mistake shall occur om working a wrong block, and so wasting the stone. here the forms of the stones are irregular, a duplicate t of templets is sent to the quarries in order that they ay be roughly scrappled into shape by the quarry-an, which saves expense of carriage, and also much of e subsequent labour of the mason.

50. It will be seen from the above brief outline how uch depends upon the accuracy of the working draw-gs, and how important it is that a mason should be thorough practical draughtsman. The large size of

many working drawings (as for instance an elevation of a church spire to an inch scale) renders it oftentimes necessary to work on them piecemeal, as it were; and great care and method are required in order to produce a correct drawing. We propose, therefore, to give a few practical hints on the management of large drawings, under the following heads, viz. Materials, Instruments, Scales, Figuring, Copying, and Platform-work.

51. *Materials.*—The best material for working drawing is stout drawing-paper mounted on linen, and well seasoned before use. This is somewhat expensive, and for common purposes strong cartridge paper will suffice, but on no account should unmounted paper be used for any but the most temporary purposes, as it is easily torn, and is spoilt by a few hours' exposure in damp weather, whilst drawings on mounted paper will sustain no material injury during many months' rough usage in the workshop and on the scaffold.

52. Indian ink* should be used for the principal lines, red and blue colour being employed for centre lines, and for such lines of construction as it may be desirable to mark in a permanent manner.

Common writing-ink should never be used, nor should any marks be made with it on a drawing, as the first shower of rain to which it may be accidentally exposed causes the ink to run into an unintelligible blot.

53. It is desirable to avoid the use of colour and shading as much as possible, as the use of the brush causes the paper to shrink in those parts where colour has been applied. Indeed, pictorial effect and delicacy

* The ink should be rubbed up fresh every time it is used. Beginners sometimes, to save trouble, content themselves with adding water to ink which has been allowed to dry on the slab. Lines drawn with stale ink are not *fast*, but will smear with the slightest moisture.

finish are out of place in large working drawings, ich should rather be executed with strong lines that ll not be effaced by dirt or by the rough handling to ich they are exposed; accuracy and neatness are all it is required.

54. *Instruments.*—The principal drawing instruments quired by the mason are—the needle-pointer, silk read, the straight edge and set-square, lead-weights, mmon and beam compasses, the ruling pen, and a set scales.

55. The *Needle-Pointer* is simply a needle fixed in a ort handle, the stump of a pencil for instance. It is ed for marking points, which it does in a permanent nner and with greater accuracy than can be obtained the use of the point of a lead pencil. The pointer is o very useful as a *rest* to keep the straight-edge in place when drawing long lines; and for copying awings by pricking through the principal points so as form corresponding punctures on a sheet of paper aced under the original drawing.

56. *Lead-Weights* are useful for a variety of purposes; t their principal use is to keep the straight-edge eady whilst drawing long lines, or when working a t square against it. Some draughtsmen keep an sistant at their side when setting out the leading lines large drawings; but it is much more convenient be quite independent of the assistance of others in ose matters, and half-a-dozen heavy weights and ew pointers will often supply the place of an extra ir of hands.

57. The *Silk Thread* is a reel of strong sewing silk, d is constantly in use for setting out and testing the curacy of lines which are too long to be drawn with e straight edge at one operation.

58. The *Straight Edge* is one of the most important implements used in drawing, as everything depends upon its accuracy. It should be made either of metal or of some tolerably hard wood of uniform texture. Wainscot and mahogany are objectionable materials, but pear-tree and sycamore answer very well. The best way of testing the accuracy of the straight-edge is to compare three together by holding them up against the light, two by two with their working edge in contact. If the light can be seen through them, or if any one of the three do not perfectly coincide with the other two, the edges must be corrected again and again, until this degree of accuracy is obtained.

59. The *Set-Square* requires the same degree of accuracy as the straight-edge; and thc straightness of its edges may be tested in the same way. To examine whether the angle contained by the working edges is exactly 90°, draw a straight line on a board, and set up a perpendicular to it by means of the set-square; then reverse the square, and if the edge, when reversed, exactly coincides with the perpendicular just drawn, the square may be considered correct. The lines for a test of this kind should be cut on the board with a drawing-knife, as a pencil line is too coarse to be a satisfactory check.

60. Both straight-edges and set-squares should be kept *flat* in a dry place. If hung up against a wall they will warp and soon become untrue.

61. The *Compasses* are used for drawing circular curves. Two pairs are required, one for curves not exceeding 8 in. radius, and another for larger curves up to 15 in. radius.

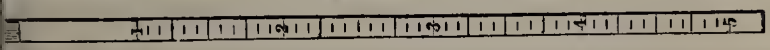
There are many different constructions of compasses, each of which has some peculiar advan-

:. The reader may consult on this subject the :eatise on Mathematical Instruments" of this Series, :re he will find engravings and descriptions of all se in common use. These instruments are expen-, but no economy will result from buying inferior s, which are worse than useless.

2. The curved rulers manufactured in Paris of thin eer, and sold under the name of *French curves*, are y useful for drawing in between points previously ermined small portions of elliptical or other curves, ch cannot conveniently be struck from centres.

3. The *Beam-Compass* is used for drawing circular ves from 15 in. to 4 ft. or 5 ft. radius. It is an ex-sive instrument, but it is indispensable in making wings on a small scale, in which the curved lines are y close together. See "Treatise on Mathematical truments" before referred to. For the purposes of king drawings, however, a very simple and excellent m-compass may be made, as shown in fig. 14. This

Fig. 14.



:rument consists of a clean pine lath $1\frac{1}{4}$ in. wide, $\frac{1}{16}$th :k, and about 5 ft. long. At one end is attached a 1 piece of veneer with a nick in it, in which to rest pen or pencil. A slip of drawing paper glued on upper side of this rule keeps it from splitting, and, ng carefully graduated, serves as a scale.

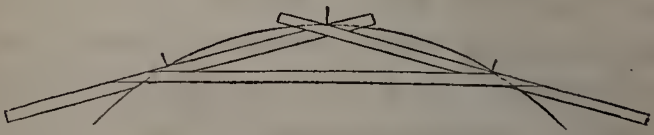
Co use this beam-compass a pointer is passed through lath into the drawing table at the proper distance n the rest, and the pen or pencil is placed in the k. The only thing to be attended to in the con-uction of the instrument is to take care that the un-

derside of the rest is raised sufficiently above the underside of the rule, so as not to smear the lines drawn with the pen. The divisions on the scale should be drawn in with curved lines, having the nick for their common centre, by which means the pointer can be set at pleasure in any part of the width of the wood.

For setting out work on a platform, a lath with a brad-awl at each end, one as a centre, and the other to mark the curves with, forms a very good beam-compass.

64. *Sweeps.*—When the radius of a curve exceeds 5 ft., it generally becomes necessary to describe it without making use of the centre; and for this purpose *sweeps*, or curved rulers, are used, by means of which the curves are drawn in between points previously ascertained by calculation. These sweeps are made of thin wood, on which the curve is first struck with the trammel as follows:—Find by calculation or otherwise three points in the curve, the middle point being in the centre between the extreme ones or nearly so. Fix a pointer at each of the extreme points, and lay against them two straight-edges, so that their intersection shall coincide with the central point. Secure the straight-edges in this position with a cross-piece, as shown in fig. 15, and the curve

Fig. 15.



may then be drawn with a fine-pointed pencil placed at the intersection of the rules, the trammel being pressed steadily against the pointers whilst the curve is drawn. Take off the superfluous wood with a plane, and the sweep is ready for use.

An instrument called a cyclograph, constructed on

principle, is sometimes used for drawing arcs of les, but it is expensive; and the use of sweeps is ferable, if the length of the curve is such that the k cannot be done without shifting the instrument, it is very difficult to make a neat junction between different portions of the curve.

method of calculating the position of a number of nts in a curve of which the radius is known, will be nd in art. 84.

5. *Scales.*— Drawing scales are made of brass, y, box-wood, and card-board. They are divided a variety of ways, some being covered with divi-ns, whilst others are divided at the edge only. se of the latter kind are called plotting scales, and preferable to the former, as the dimensions can be ked off at once on the paper along the edge of the e, whilst the others require them to be transferred n the scale to the paper with compasses, an opera- which tends to deface the scale, and introduces a nce of error, which it is well to avoid.

he engine-divided card-board scales, manufactured Holtzapffel and Co., possess many advantages, of ch the principal ones are, their extreme accuracy their low price. They are sold at 9*s*. the dozen; , although made of perishable material, will last ny years. Box-wood plotting-scales 12 in. long are ally sold at about 4*s*., and ivory scales of the same gth at about 10*s*.

6. Before commencing a large drawing, it is advisable ut a strip from the edge of the paper, and to make n it a scale of the whole length of the intended wing. The use of a scale of this kind saves much e that would otherwise be spent in setting off, and cking long dimensions by numerous applications of

a comparatively short scale; and, the scale being kept rolled up with the drawing, will generally contract and expand with it, and thus obviate the perplexing difficulties which arise from the expansion and contraction of the paper from atmospheric changes.

Independently, however, of the constant variation which is daily taking place with every change in the weather, all paper is subject, when worked upon, to a certain amount of permanent contraction, which must be allowed for in making the paper scale. The amount of this correction in the scale must depend upon the seasoning the paper has received, and the texture of the paper itself, so that no precise rule can be given for it. During many years' observation of parish and railway plans, we have found it vary from $\frac{1}{200}$ to $\frac{1}{400}$; and a mean between the two may be safely taken; that is, the length of each foot on the scale should be 1·303 ft. After a very few days' work, the warmth of the hand will cause the paper to shrink to the correct length, or nearly so.

67. Both box-wood and ivory scales are subject to expansion and contraction, but the amount of this is too trifling to be taken into account.

68. *Standard Scale.*—In order to ensure uniformity in the dimensions of a large building, every master mason should keep a standard metal scale very accurately divided, by which all the scales used in making the working drawings, and the rods employed in setting out the work, should be carefully tested. Unless this is done, it is very difficult to keep the work exact, particularly in erecting bridges of large span.

69. *Centre Lines.*—On commencing a drawing, two centre lines at right angles to each other should be drawn through the middle of the work, of the whole

;th and breadth of the paper. Lines parallel to ;e should be drawn in pencil at regular distances, 'esponding to some even division of the scale, divid- the paper into squares or rectangles of convenient . The intersections of the lines should be punc- :d with a needle, and marked in faint colour thus +, r which the pencil lines may be rubbed out.

'his precaution is of great use in keeping the work fectly true and square, as the divisions are a com- .e check on the parallelism of the lines of the draw- and afford a ready means of drawing lines in a :n direction, on any part of the paper, without the essity of reference to the principal centre lines.

'hey also are of great use in ascertaining the exact)unt of contraction which the paper may undergo n time to time, and in checking the distances from centre lines.

'0. *Figuring.*—The manner in which working draw- s are figured is of considerable importance. The izontal dimensions should be referred to centre lines :ked on the *whole* of the plans, and the positions of the principal points should be obtained in the exe- ion of the work by direct reference to the centre :s, and not by measurement from intermediate points. is precaution confines any trifling error to the spot ere it occurs, instead of its being carried forward ough the work, as would otherwise be the case. To .ble this to be readily done, two sets of dimensions l be required: 1st, the dimensions from point to nt; and 2nd, those from the principal points to the tre lines. If any clerical error be made in figuring ' of the dimensions, it can by this means also be ected and corrected, as every leading dimension is en once in gross, and can be also obtained by addi-

tion in two other ways. In spite of the utmost care errors will creep into the working drawings, and those who have lost valuable time through some apparently trivial mistake in a figure, can appreciate the advantage of being able to *correct* mistakes as well as to detect them.

71. Elevations and sections should be figured on the same principle as the plans, vertical lines corresponding to the centre lines of the latter being marked upon them whenever practicable.*

The vertical heights should all be referred to a common datum line, which should coincide, if possible, with some leading line in the design. In the execution of the work, the height of the datum line should be permanently marked by a stout stake driven firmly into the ground at the proper level.

72. It generally happens in the execution of large works that their levels require to be determined with great precision. Before making the working drawings therefore, it is always advisable to put down a permanent mark at the intended site, and to ascertain its height with reference to the levels of the proposed works. In figuring the elevations and sections, the position of the datum line with reference to this mark must be accurately noted, and there will then be no difficulty when commencing operations in ascertaining the proper level at which to start the work.

73. *Copying Drawings.*—To make a correct duplicate of a large drawing is a work of some difficulty. The most correct method is to draw the whole afresh to scale, but this is very tedious. Two methods are in use for abridging the labour of the draughtsman. One is

* This is done on the assumption that the work is intersected by vertical planes passing through the centre lines of the plans.

ay the drawing *over* the blank paper, and to prick ough the leading points with a needle. The copy is n easily lined in between the points thus formed. e other method is to place a sheet of transparent ber over the drawing, and having secured the two ether, so as to prevent all possibility of their shifting, copy is drawn on the transparent paper.

Both these methods possess the common defect of ducing a copy of the original, not of exactly the ne size, but, from the shrinking of the paper, a little aller, and in consequence the real scale will be less n the nominal one. And this is not the only evil, in a large drawing the contraction of the paper is en so irregular, that the straight lines become twisted re or less; and these irregularities becoming still re distorted in the copy, the latter is of little value. ere is also great difficulty in pricking off a large awing with accuracy, as it is difficult to get the paper lie sufficiently flat for that purpose.

74. The method the author would recommend is, first, divide the blank paper into squares or rectangles nilar to those of the original; next, to make a care- tracing of the latter, marking the divisions of the ares; and, lastly, to lay this tracing on the blank per, and to prick it through, adjusting the work in h square to the new lines. By this means the ors of shrinkage and distortion will be corrected, d the copy, when quite finished, will be of exactly e same size as the original. The tracings, being efully laid aside, will serve for any number of copies at may be required.

75. *Platform Work.*—The laying down of the work its full size on a platform is done by methods pre- ely similar to those in use for making large drawings

on paper, except that all the instruments are on a larger scale, and that the brad-awl and chalk line take the place of the needle and silk thread. To ensure accuracy and uniformity in the work, the rods used for setting off the dimensions should all be divided from the standard scale referred to in a previous article.

Great care should be taken to render the platform perfectly level and quite firm, so that there shall be no chance of any of the lines shifting their position.

LINEAR DRAWING.

STRAIGHT LINES.

76. *To draw a straight Line between two given Points.*—Insert a needle at each of the given points; press the straight-edge gently but firmly against them, and draw the line with the pen or the pencil held against the straight-edge, so as exactly to range with the centres of the needles.

If the line to be drawn be of considerable length, say 15 ft. or 20 ft., so that it cannot be drawn with the straight-edge at one operation, the silk thread must be used as follows:—

Insert the needles at the extremities as before, and strain the silk tightly between them; puncture the paper in the line of the thread at short intervals, and draw the line in between the points thus founded as before.

This method should be always resorted to where extreme accuracy is required. A common but vicious mode of drawing long lines is to produce them with the straight-edge until they are of the required length; but this method is not susceptible of minute accuracy.

77. *To draw straight Lines parallel to a given straight*

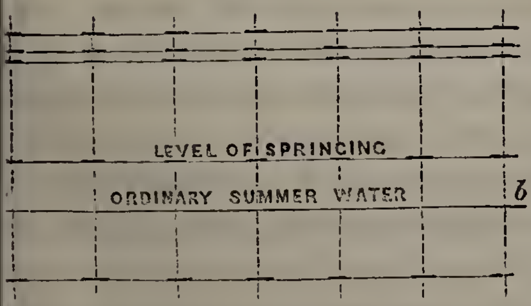
e.—If the lines to be drawn do not exceed 2 ft. in ;th, they may be drawn by placing the working edge a large set-square to coincide with the given line, fixing a straight-edge against the bottom of it, ping it steady with two needles and a weight or two necessary. All the lines drawn with the set-square l of course be parallel to each other. If the lines to drawn are parallel to either of the centre lines, nothing re will be required than to set the straight-edge to nearest divisions of the paper.

If the lines are very short, a small set-square and aight-edge may be used, the latter being steadied h the left hand, whilst the set-square is moved, and lines drawn with the right hand.

For short lines also, the parallel ruler is much used professional draughtsmen, but it requires a practised nd to ensure perfect accuracy in its use, and we have t, therefore, mentioned it previously.

Long lines must be drawn with the straight-edge rough points previously marked off. Let it be required, for instance, in making an elevation of a bridge, to draw a series of lines parallel to the line *a b*, fig. 16, which we will suppose to be 20 ft. long.

Fig. 16.

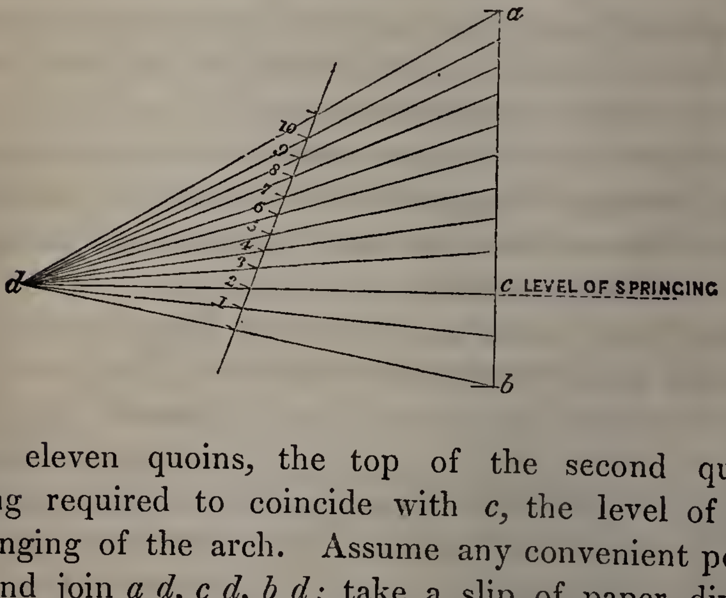


ect perpendiculars to *a b* at such distances apart that e straight-edge will extend over three divisions or more, d on these perpendiculars set off by scale the exact stances from *a b* at which the parallel lines are to be awn. This is best done by setting off the distances a strip of paper, and pricking them off on each per-

pendicular. The lines can then be drawn through the points thus found with great accuracy, as the slightest error in any part of a line is at once detected by reference to the more distant points.

78. *To divide a straight Line into a given Number of unequal Parts, which shall diminish in regular Progression, and so that a given Division shall pass through a given Point.*—Let *a b*, fig. 17, be the height of the pier of a bridge, which it is proposed to divide

Fig. 17.



into eleven quoins, the top of the second quoin being required to coincide with *c*, the level of the springing of the arch. Assume any convenient point *d*, and join *a d*, *c d*, *b d*; take a slip of paper, divide its edge into eleven equal parts of convenient size, and slide it over the triangle until the zero, and the 2nd division, are respectively on the lines *b d*, *c d*, whilst the last division is on the line *a d*. Prick off the points 1, 3, 4, 5, 6, 7, 8, 9, 10, and draw lines through them, intersecting the line *a b*, which will then be divided as required.

The method of arranging the sizes of the courses of a building, so that the first and last shall be of given heights, is precisely similar.

he above is a very convenient practical rule, but only be applied within certain limits.

ANGLES.

). *To set off a right Angle.*—There are three ways oing this in common use. It may be done on a small e mechanically with a straight-edge and set-square. a large scale it may be performed by describing with n-compasses a triangle, of which the sides are re- tively as 3, 4, and 5; or by describing two isosceles igles on a common base, of which the centre is the t through which the perpendicular is to pass, see fig. plate 1. This last method is the most perfect of the e, as the accuracy of the work is at once checked rying with a silk thread whether the vertices of the igles range with the centre of their common base.

). *To set off an acute Angle.*—This may be done small scale by pricking off the angle from the edge protractor; but this method is inapplicable to large vings, as the sides of the angles would have to *roduced* from a line probably not exceeding a few es in length.

he best method of setting off an angle, of which the s are of considerable length, is to describe with beam passes an isosceles triangle of which the base and s are respectively as the chord and radius of the angle. length of the chord is obtained as follows: since the d of any arc is double the sine of half the angle sub- ed by that arc, we can find the chord for any angle, aking from a table of natural sines the sine of half angle and doubling it.* Tables of natural sines are ulated for radius = 1, the length of the sines being n in decimals; in plotting an angle by this means it

nstead of *doubling* the sine, we may use *half* the radius, which is a simpler plan, although the principle is not so immediately apparent.

is therefore necessary that the scale should be divided decimally, and that the radius chosen should be ten, or some multiple of that number.

Example.—To set off an angle of 70°, the sides to be not less than 8 ft. long. Look in the table for the natural sine of 35°, which is ·5735764. The length of the chord will be twice this, or 1·1471528. Taking the radius in inches, the nearest convenient number will be 100, and accordingly the decimal point must be shifted two places, making the length of the chord 114·71528 inches.

It is always desirable in plotting angles, that the points found should be *beyond* the work, and not within it, so that there may be no necessity for *producing* their sides.

81. *An Obtuse Angle* is plotted by producing one of the sides and setting off the supplement of the required angle.

82. *Measurement of right-angled Triangles.*—In any right-angled triangle, if one side and one of the acute angles be given, the remaining sides can be readily found by calculation, with the help of a table of sines, cosines, secants, and tangents. We presume the reader to be familiar with the method of doing this, but it may be useful here to insert the formulæ.

In the right-angled triangle $a\ b\ c$, fig. 19, plate 1. Let $\angle\ a\ b\ c$ be the given angle—the $\angle\ b\ a\ c$ will of course be its complement.

1st, Let the hypothenuse $a\ b$ be the given side.

$$\text{then side } a\,c = a\,b \times \text{sine} \angle\ a\,b\,c$$
$$\text{and side } b\,c = a\,b \times \cos \angle\ a\,b\,c.$$

2nd, Let the given side be one of those containing the right angle, as $b\ c$.

$$\text{then side } a\,b = b\,c \times \sec \angle\ a\,b\,c$$
$$\text{and side } a\,c = b\,c \times \text{tang} \angle\ a\,b\,c.$$

: any two sides are given, the third side may be ıd arithmetically in the absence of a table of sines. f the hypothenuse be one of the given sides, then the $a\,c = \sqrt{a\,b^2 - b\,c^2}$, and side $b\,c = \sqrt{a\,b^2 - c\;^2}$. f the two sides containing the right angle be given,

$$\text{then side } a\,b = \sqrt{a\,c^2 + b\,c^2}.$$

'he solution of right-angled triangles is very fully lained in Mr. Heather's "Treatise on Mathematical truments,"* to which we would refer the reader who ot familiar with the subject: the foregoing cases are :ely inserted here to assist the memory.

CURVED LINES.

33. *Circular Curves.*—The following problems will found useful.

Given the Span and Rise of a Circular Arc, to find Radius.

Let r = radius.

s = half-span.

v = rise, or versed sine.

Then $r = \dfrac{s^2 + v^2}{2v}$.

Demonstration (fig. 20, plate 1).—Let $a\,d\,e$ be the : of which the radius is required: $a\,b$ the half-span, d $b\,d$ the rise, and let c be the centre of the circle.

Join $a\,c$, $d\,c$, and $a\,d$; bisect $a\,d$ in f and join $f\,c$. e right-angled triangles, $b\,a\,d$, $f\,c\,d$, are similar, having common angle $f\,d\,c$;

$$\text{therefore, } b\,d : d\,a :: f\,d : d\,c = \frac{f\,d \times d\,a}{b\,d}.$$

* "A Treatise on Mathematical Instruments," in the Rudimentary atises.

But, $f\,d = \frac{d\,a}{2}$.

$$\therefore d\,c = \frac{\frac{d\,a}{2} \times d\,a}{b\,d} = \frac{d\,a^2}{2\,b\,d} = \frac{a\,b^2 + b\,d^2}{2\,b\,d} = \frac{s^2 + v^2}{2\,v}.$$

Q.E.D.

84. *The Radius being given, to find the Length of an Offset at any given Point on a tangent Line.*

Let r = radius.

t = distance on tangent line from the point of contact.

o = offset.

Then $o = r - \sqrt{r^2 - t^2}$.

Demonstration (fig. 21, plate 1).—Let $a\,e$ be the given tangent, c the centre of the circle, and $e\,b$ the offset, of which the length is required. Join $a\,c$, $b\,c$, and draw $b\,d$ parallel, and, by construction, equal to $a\,e$. Then $e\,b = a\,d = a\,c - d\,c$.

Now, $d\,c = \sqrt{c\,b^2 - d\,b^2}$

$\therefore e\,b = a\,c - \sqrt{c\,b^2 - d\,b^2} = r - \sqrt{r^2 - t^2}$. Q.E.D.

85. In designing large works it is often requisite to connect two straight lines by a circular curve. Before the offsets can be calculated for this purpose the following data must be known, viz. the angle formed by the lines to be connected, the radius of the curve, and the distance from the point of intersection to the points of contact. The first of these conditions is generally determined by the circumstances of the case; with regard to the second and third conditions, one of the two must be assumed and the other calculated from it.

86. First Case.—*The Distance of the Points of Contact from the Point of Intersection being given, to find the Radius.*

n the lines to be connected, let b and d (fig. 22, plate be the points of contact, which will necessarily be idistant from the point of intersection.

Join $b\,d$; bisect it at e, and join $a\,e$; then

$$\text{radius} = \frac{b\,e \times a\,b}{a\,e}.$$

Demonstration.—Let c be the centre of the circle; 1 $b\,c$ and $e\,c$. The right-angled triangles $a\,b\,e$ and b are similar, having the angle $b\,a\,c$ common to h;

$$\therefore a\,e : b\,e :: a\,b : b\,c = \frac{b\,e \times a\,b}{a\,e}. \quad \text{Q.E.D.}$$

The construction made use of in the above problem useful for determining the radius of curvature of a ıg-wall of a bridge.

Thus (fig. 23, plate 1), let $d\,f$ be the front of the dge, d the point at which the curve is to commence, and b the point at which the wing-wall is to l. Join $b\,d$; bisect it at e, and erect the perpendicular $e\,a$ cutting $d\,f$ produced in a; join $a\,b$, and calate the radius as above.

37. Second Case.—*The Radius being given, to find Distance of the Points of Contact from the Point of ersection.*

To do this, assume any approximate points, as $b_1\,d_1$. 24, plate 1), and find the corresponding radius $b_1\,c_1$.

Let r = given radius = $b\,c$,

r_1 = assumed radius = $b_1\,c_1$,

t = required length on tangent line = $a\,b$,

t_1 = assumed length on tangent line = $a_1\,b_1$,

n, $r_1 : t_1 :: r : t = \dfrac{t_1\,r}{r_1}$.

38. *To find the length of a Circular Arc.*—If the radius

is not known, it may be found as described in art. 83. Let $a\,b\,e$ (fig. 25, plate 1) be a portion of the circumference of a circle, of which the radius $= r$. Assume any convenient angle, as $a\,c\,b$, and calculate its chord as in art. 80. Set it off on the curve with beam-compasses, and measure the remainder, $b\,e$, as a straight line, which may be done without sensible error, by assuming such an angle as will leave a very small remainder.

The semi-circumference of a circle is equal to radius $\times 3{\cdot}1416$; the $\frac{1}{180}$th part, or that corresponding to a single degree, is therefore equal to radius $\times {\cdot}017453$. If we call n the number of degrees in any angle, $a\,c\,b$, we have for finding the length of any arc, $a\,b$, the simple formula: length of arc $= n\,r \times {\cdot}017453$.

Example.—Let $r = 134$ ft. On examination let it be found, that the number of degrees which will give the smallest remainder is 70. The length of the arc, $a\,b$, will therefore be 70×134 ft. $\times {\cdot}017453 = 163{\cdot}70914$ ft.; to which must be added the remainder, $b\,e$, the sum of the two making up the whole length of the arc $a\,b\,e$.

89. This problem is of great service in ascertaining the length on soffit of an arch of known span and rise, either for the purpose of dividing the arch-stones, or for laying down a development of the soffit.

Its converse is equally useful in setting off on a circular arc, a distance equal to a given straight line. Let it be required on the curve $a\,b\,e$ (fig. 25, plate 1) to set off a portion, $a\,e$, that shall be equal to a given straight line, say 164 ft. long.

Let the radius of the curve be 134 ft. as before, then $\dfrac{164}{134 \times {\cdot}017453} = 70{\cdot}14$. Rejecting the decimals, find the chord of $70°$, which for radius $= 134$ ft. is $153{\cdot}718$ ft.; and the length of the arc $a\,b = 163{\cdot}709$ ft.

lucting this last quantity from 164 ft., we find the
ıainder $b\,e = \cdot 291$ ft.

'o set off the required distance on the curve, set off
chord $a\,b = 153 \cdot 718$ ft., with beam-compasses, and
n b set off $b\,e = \cdot 291$ ft.; the length of the arc $a\,b\,e$
be 164 ft., as required.

0. It is often necessary to transfer the divisions of
arch-stones from the development to the elevation
.n arch. The best way of doing this is to set them
from the development on a long lath, and to bend
latter round the curve in the elevation, to which the
sions can then be readily transferred. This method
fines any little inaccuracy to the joint where it occurs;
if it be attempted to set off the joints stone by stone
ı compasses, great difficulty will be experienced in
cing the minute allowance which is necessary for the
erence between the length of the curve included
ween two joints and the corresponding chord, which
he distance to which the compasses must be set.

1. *Method of describing an Ellipse.*—On a small
e, and where it is desirable to avoid defacing the
er with the points of the compasses,—as, for example,
rawing the coping of a curved wing-wall,—the sim-
st mode of proceeding is to find a number of points
he curve, and to connect them by means of a curved
r, the edges of which are cut into a continuous series
urves of different radii.

ny number of points in an ellipse may be found as
ows:—Let $a\,f$, $e\,f$ (fig. 26, plate 1) be the respective
i-diameters of the ellipse. With f as a centre and
ınd $e\,f$ as radii, describe two quadrants. Divide the
er quadrant into any convenient number of divisions,
, 2, 3, and draw the lines $1\ 1_1 f$, $2\ 2_1 f$, $3\ 3_1 f$, cutting
lesser quadrant at 1_1, 2_1, 3_1. From the points 1 and
lraw lines parallel to the diameters cutting each

other at *b*, then *b* will be a point in the ellipse. In a similar manner will be found the points *c* and *d*.

92. When an ellipse has to be drawn on a large scale, the best way is to strike it from centres; and, although this is only an approximation, no portion of an ellipse being a circular curve, no appreciable error will result if a sufficient number of centres be taken.

The following method is very simple. Having found a number of points in the curve, as *b*, *c*, *d*, draw the chords *a b*, *b c*, *c d*, *d e*. Bisect *d e* with a perpendicular cutting *f e* produced in *g*; then *g* will be the centre for the portion of the curve between *e* and *d*. Join *d g* and bisect *c d* with a perpendicular cutting *d g* in *h*; then *h* will be the centre, for the portion of the curve between *c* and *d*. The centres *i* and *k* are found in a similar manner.

93. To set out an ellipse on a platform; when the scale is such that the operation must be performed without making use of centres, we must proceed rather differently.

Divide the right angle contained between the two semi-diameters into any convenient number of angles, as *a f* 1, *a f* 2, *a f* 3 (fig. 27, plate 1), and multiply their respective sines and cosines, the former by radius *e f*, and the latter by radius *a f*. This will enable us to lay down the points *b*, *c*, *d*, by means of offsets from the diameters, as shown in the figure.

The curves *e d*, *d c*, &c., must be drawn in with curved rules, made as directed in article 64.

To find the radii, draw the chords *e d*, *d c*, &c.; bisect the angles formed by their intersections with short lines as shown in the figure. On these bisection lines, let fall perpendiculars, as $d\,d_1$, $c\,c_1$, &c., and the several radii can then be calculated as in article 83.

94. An ellipse of moderate size can also be struck on a platform, from the foci, as follows:—

'rom *e* as a centre (fig. 28, plate 1), with radius *a f*, ;ribe arcs cutting *a a* in *m*, *l*, which will be the foci he ellipse. Put in a brad-awl at each of the foci, round them pass an endless cord of such length ;, when strained tight, it will just reach the point *e*. : curve may then be drawn in with a brad-awl or a ving knife pressed firmly against the cord.

'his is a very expeditious method; but it requires siderable management to produce an even line, and iot susceptible of minute accuracy. The practical culty arises from the elasticity of the cord.

5. *To draw a Line perpendicular to the Circumfe- :e of an Ellipse at any Point,* as *n* (fig. 28, plate 1). oin *m n*, *n l*: a line bisecting the angle *m n l* will be pendicular to the curve at *n*.

'his problem is required in drawing the joints in the ation of an elliptical arch.

6. *Spiral Curves.*—In making drawings of oblique lges, numerous projections of spiral lines have to be wn; and it is of importance that this should be done 1 great exactness. The best method of accomplish- this, is to make a very accurate template for each of curves in cardboard or veneer, which will ensure fect uniformity in the work, and also save much of draughtsman's time.

'7. *Principles of Projection.*—The working drawings he mason may be classed under two heads:—First, metrical projections; and, secondly, developments of faces. The geometrical projections are always made either horizontal or vertical planes; the drawing ıg called in the first case a *plan,* and in the second e an *elevation.* When the plane of projection cuts object represented in a vertical direction, the draw- is called a sectional elevation, or, in brief, a *section.*

It will be observed that most plans of buildings are, in fact, horizontal sections, but the term is technically applied to vertical projections only. Developments are representations of the surfaces of solids, as they would appear if unwrapped and laid flat, and are made use of to obtain the dimensions of surfaces which, from their inclined position, become foreshortened both in plan and section; and for the delineation of curved surfaces, which cannot be accurately represented in any other manner.

The nature of plans and elevations may be clearly understood by considering them as perspective projections on a sphere of infinite radius of which the centre is the point of sight.

98. The following properties of geometrical projections should be kept in mind.

Lines.—All horizontal lines will be represented of their true length and curvature on plan.

All vertical straight lines will be represented of their true length in elevation.

All lines inclined to the horizon will be more or less foreshortened in plan.

99. The length of any inclined straight line may be obtained from the plan and elevation by a simple construction. Thus to find the length of the arrises of a square pyramid: let $a\,c$ (fig. 29, plate 1) be the vertical height of the pyramid, and $c\,b$ the half-diagonal of the base; then the required length $a\,b$ is the hypothenuse of the right-angled triangle $a\,c\,b$, and can be formed by constructing the triangle and measuring the hypothenuse, or by calculation, since $a\,b = \sqrt{a\,c^2 + b\,c^2}$.

100. *Surfaces.*—Horizontal planes will be represented by identical figures on plan, and by straight lines in elevation. Thus the plan of a circle parallel to the horizon will be a circle, and its elevation will be a straight line;

iclined to the horizon, its plan will be an ellipse in positions except the vertical, when its plan will be a ight line, and its elevation a circle, a straight line or ellipse, according to the position of the plane of ation.

01. *Solids.*—The plan of a right cone standing on base will be a circle, and its elevation a triangle.

'he plan of a right cylinder, similarly placed, will be rcle, and its elevation a rectangle.

'he plan and elevation of a sphere will always be les.

'igs. 30, 31, 32, 33, and 34, explain the manner of jecting the plan and elevation of the prism, pyra-, cone, cylinder, and sphere.

Fig. 30.

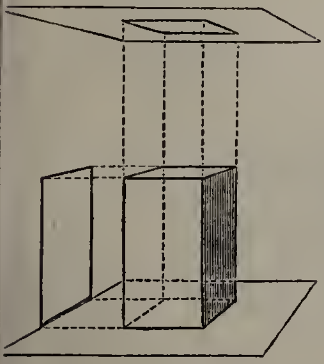


Fig. 31.

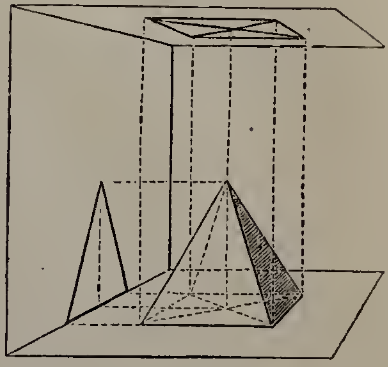


Fig. 32.

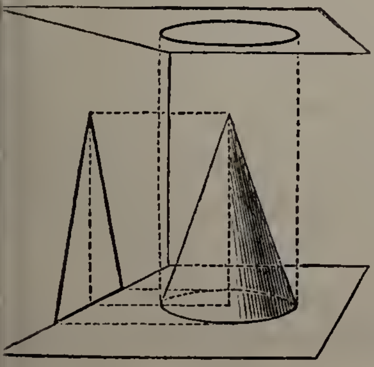


Fig. 33.

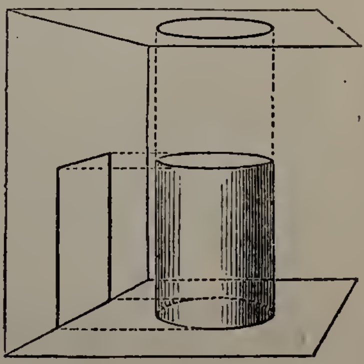
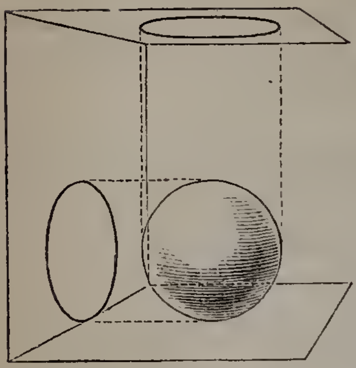


Fig. 34.



102. *Sections.*—The following properties of the cone, cylinder, and sphere, should be borne in mind:—

Every plane section of a cone perpendicular to its axis will be a circle.

Every plane section of a cone passing through the vertex and the base will be an isosceles triangle.

Every plane section of a cone cutting its axis at an acute angle, greater than that made by the slant side, will be an ellipse, or a segment of one.

Every plane section of a cylinder parallel to its axis will be a rectangle.

Every plane section of a cylinder perpendicular to its axis will be a circle.

Every plane section of a cylinder cutting the axis obliquely will be an ellipse, or a segment of one.

Every plane section of a sphere will be a circle.

103. The sections above enumerated can be projected in any position with very few lines; the projection of an ellipse being always either a straight line, a circle, or an ellipse, and the only data required for drawing the latter figure are the lengths of the major and minor axes. There are however many other curves, such as those formed by the intersection of two curved surfaces, which are not so easily described, and which require a considerable amount of projection, and transference of lines, in order to represent them accurately.

104. *Developments.*—The curved surfaces of solids may be classed under two heads; 1st, those with which

traight-edge will coincide in one direction, as the faces of the cone and cylinder; and 2nd, those with ich a straight-edge will not coincide in any direc- 1, as the surface of a sphere. The former are some- es called curved planes, and their development, in case of the cone and the cylinder,* is very simple. e latter can only be developed approximately, be- se it is impossible to bend a plane, so as to coincide h a spherical, surface.

05. The development of the curved surface of a it cone will be a sector of a circle, whose radius is slant height of the cone; the length of the arc ng equal to the circumference of the base of the ie; see fig. 35.

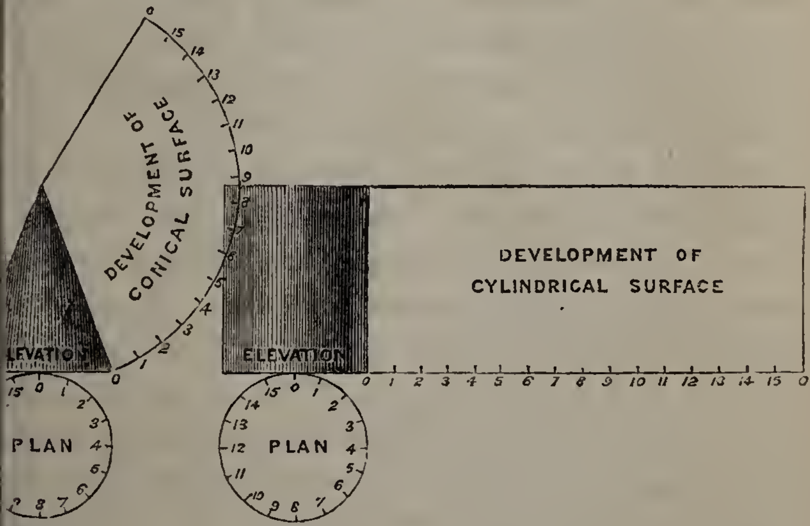


Fig. 35. *Fig.* 36.

06. The development of the curved surface of a it cylinder will be a rectangle, whose length is the al length of the cylinder, and whose width equals circumference of its base; see fig. 36.

Winding surfaces cannot be developed even approximately, being ex in one direction, and concave in the opposite.

107. The surface of a sphere may be developed approximately in three different ways; 1st, it may be considered as a polyhedron, of which each side will be a plane surface; 2nd, it may be divided into gores like the gores of a balloon, in which case each gore will be a portion of a cylindrical surface; lastly, it may be divided into zones, each of which may be treated as a portion of a conical surface. This last method is the one most practically useful, and will be understood by inspection of fig. 37, plate 4.

PROJECTIONS OF THE CONE.

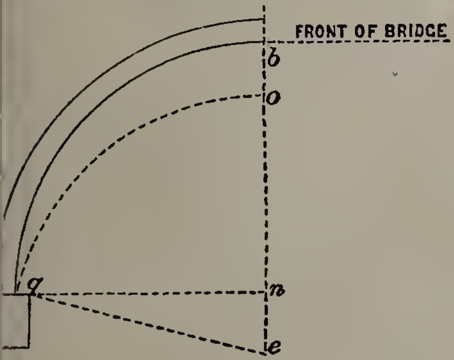
108. The several projections of the cone which we are about to describe are principally required by the mason in the execution of battering walls, on a curved plan, which form portions of hollow cones. The projections and development of a right cone have been explained above, in arts. 101 and 105.

109. *To draw the Projections of an inverted Cone from which an oblique Frustum has been removed.*—In fig. 38, plate 4, side elevation, let $b\ d\ e$ be the inverted cone, and $b\ d\ m$ the frustum removed. Bisect $b\ m$ in n, and through the point n draw $e_1\ n\ o\ b_1$ parallel to the base, and cutting the axis of the cone at e_1. Draw $b\ b_1$ parallel to the axis of the cone, cutting $e_1\ n\ o\ b_1$ in b_1, and making $e_1\ b_1$ equal to $c\ b$, the radius of the base. It may be easily shown that $e_1\ n_1 = o\ b_1$. In the *plan* draw the diameters $b\ e\ d$ and $a\ e\ c$ perpendicular to each other, so that all straight lines drawn on the plane of intersection, parallel to $a\ e\ c$, shall be horizontal. Set off $e\ n$, $b\ o$ respectively equal to $e_1\ n$, $o\ b_1$ in side elevation. With radius $e\ o$, and centre e, describe the quadrant $o\ q\ r$, and through n draw $p\ n\ q$ parallel to $a\ c$, cutting the arc $o\ q\ r$ in q, and make $n\ p = q\ n$.

t off $n\,m = n\,b$; then $b\,m$ and $q\,p$ will be respec-ely the major and minor axes of the ellipse, which is : horizontal projection of the oblique section of the ıe.

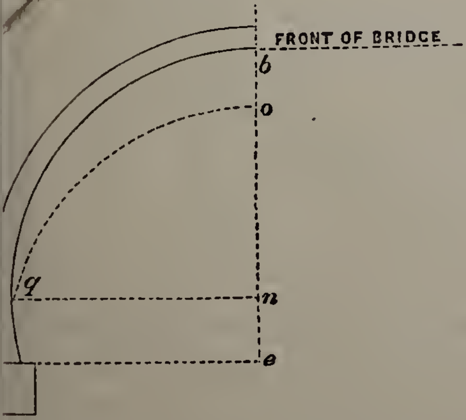
Since by construction $n\,b = e\,q$, the length of the ni-axis minor $q\,n = \sqrt{n\,b^2 - e\,n^2}$. In ordinary cases, : difference of the lengths of the major and minor es is so small, that the quarter ellipse may be drawn thout sensible error, as a circular curve, with radius) and centre on $q\,p$, removed from n by the differ-ce between the semi-axes.

Fig. 39.



110. It will be seen by inspection of fig. 39 that in building a curved wing-wall, terminating in a pier as there shown, the horizontal distance $b\,n$ (fig. 39) should not exceed $b\,n$ in fig. 38, plate 4: or the coping would have a very unpleasing appearance, as shown in fig. 40.

Fig. 40.



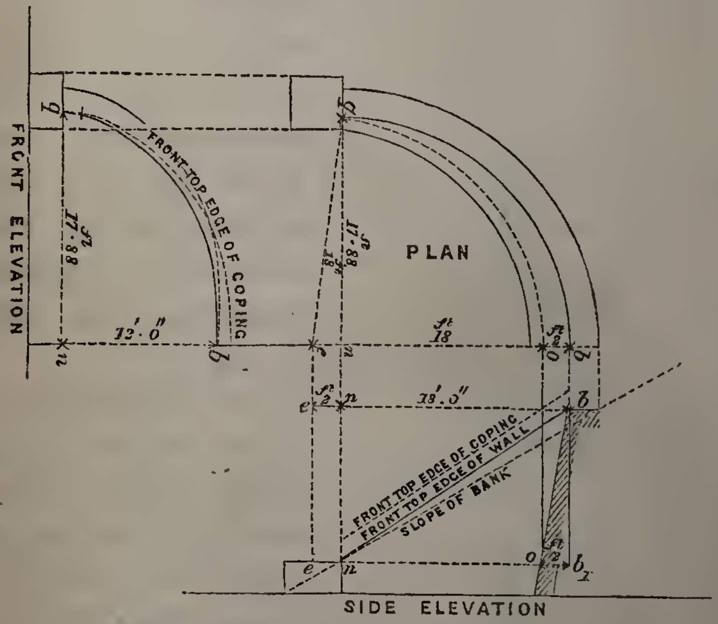
111. When the plan of the coping is less than a quarter ellipse, the side of the pier must be made square with a tangent to the ellipse at the point of intersection with the wing-wall.

112. *To draw the front Elevation.*—Set off $b\,n = b\,b^1$

in side elevation, and $nm = bn$. Through n draw qnp parallel to ac, and set off $nq = nq$ in plan; and $np = nq$. Then qp, bm are respectively the major and minor axes of the ellipse $bqmp$, which is the vertical projection of the oblique section of the cone.

113. In drawing curved wing-walls to support an embanked approach to a bridge, the data given or assumed are the height bb_1; the inclination of the slope of the bank, which should coincide with that of the top of the wall;* and the batter or slope of the face of the wall. As we have often found beginners to be very much at a loss how to draw the plan and elevation of such a wall without covering the paper with unnecessary lines, we subjoin an example.

Fig. 41.



* The coping of a wing-wall is sometimes made to stand up *above* the slope of the bank, but this has an awkward appearance. To make the top of the wall form a spiral plane, as recommended in "Nicholson's Railway Masonry," is perhaps the worst plan that can be adopted as the coping is not parallel to the slope of the bank.

To avoid confusing the diagram the coping of the wall is omitted.

Let $b\ b_1 = 12$ ft.

Let the slope of the top of the wall be $1\frac{1}{2}$ horizontal to 1 vertical.

Let the batter of the face of the wall be 1 horizontal to 6 vertical.

Then $n\ o\ b_1 = 12$ ft. $\times\ 1\frac{1}{2} = 18$ ft.

and $e\ n = o\ b_1 = \frac{12}{6}$ ft. $= 2$ ft.

Transfer these dimensions to the plan.

$$n\ b = e\ o = e\ q = 18 \text{ ft.}$$

$$q\ n = \sqrt{n\ b^2 - e\ n^2} = \sqrt{324 - 4} = 17{\cdot}88 \text{ ft.}$$

The *plan* of the front line of the top of the wall will therefore be a quarter ellipse, whose semi-diameters are respectively 18 ft. and 17·88 ft.

The *Front Elevation* of the front line of the top of the wall will be a quarter ellipse, of which the semi-diameters are respectively 12 ft. and 17·88 ft.

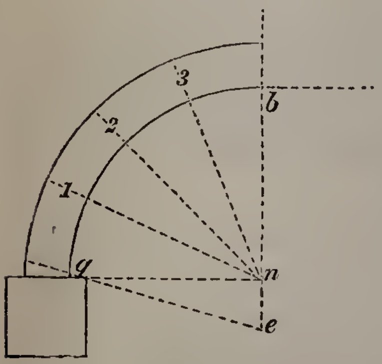
114. *Development of the Cone.*—Divide the circumference of the base into any convenient number of equal parts as shown in the plan (fig. 38, plate 4) by the points f, h, &c., and transfer these divisions to the side elevation. From the new points thus found draw lines radiating to the apex of the cone, cutting $b\ m$ in f_1, g_1, h_1, &c. Through f_1, g_1, h_1, &c., draw lines parallel to the base, and cutting the sides of the cone. Having drawn the development of the slant surface of the cone, divide the arc $b\ d\ b$ to correspond with the divisions of the base in plan, and draw the radiating lines $f\ e$, $g\ e$, $h\ e$, &c., corresponding to the radiating lines in the side elevation. From the points found on the slant side of the cone, with e as a centre, draw circular arcs cutting the radiating lines $f\ e$, $g\ e$, $h\ e$, &c., in f_1, g_1, h_1, &c. A curve drawn through these last points will be the develop-

ment of the line bounding the oblique section of the cone.

The oblique section of the cone will form an ellipse, whose major axis $= b\,m$ in the side elevation, and whose minor axis $= q\,p$ in the plan.

115. *To project the Lines of the Coping of a curved Wing-Wall.*—The coping of a curved wing-wall is worked in such a way that its bed shall be everywhere level in a direction perpendicular to the curve of the wall. Thus, fig. 42, any number of lines, as 1, 2, 3, drawn perpendicular to the curve of the wall, will be horizontal lines. If the coping bed were made level in the direction of the centre of the cone, as shown by the line $e\ q$, it is evident that the intersection of the coping with the pier will not be a level line, the front of the coping being higher than the back, which would have a most unsightly appearance.

Fig. 42.



116. If the top of the wall be worked as above described, the front and back edges will lie in *planes** of different inclinations, intersecting each other on the line $q\,n$. It is usual to make the *back* of the wall coincide will the slope of the bank. The front line will therefore be found in side elevation, without any transference of lines, by setting off the width of the top of the wall

* If the front and back edges of the top of the wall are made to lie in *planes*, so as to be represented in side elevations by straight lines, all level lines in the coping bed will be curved, and not straight; but the curvature is too small to be measured in so short a distance, and cannot be distinguished from a straight line.

m the top of the slope as shown in fig. 41, and draw a straight line from the point thus found to n. In nt elevation all the lines of the coping will be elliptil curves.

17. It may be necessary to remark that the top and tom lines of the coping in side elevation will not be allel to each other. This arises from the thickness ng set off at the top in a vertical, and at the bottom an inclined direction, so that the lines will diverge m the top downwards. (See fig. 41.)

18. *Intersection of a Cone and a Cylinder* (fig. 38, te 4).—This is a problem of not unfrequent occurce, as in the case of a cylindrical culvert passing ough the curved wing-wall of a bridge. In a diam here given the axes of the cone and cylinder are de to intersect each other at right angles.

In front elevation the projection of the intersection the cylinder with the slant surface of the cone, will a circle. Draw two diameters, the one parallel to base, the other to the axis of the cone. Divide the cumference of the circle into any convenient num of equal parts, as 16. Divide one of the diameters o 8 parts by perpendiculars drawn through the divins on the circumference, and transfer these divisions the axis of the cone in side elavation, as shown at a_2, c_4, &c. Through these points draw lines parallel to base, and cutting the slant side of the cone in 1, 2, 3, . Transfer the divisions on the diameter of the inder to the diameter $a\ c$ in plan, and through the ints thus found draw the perpendiculars $a\ a_2$, $b\ b_2$, &c. aw the diameter $b\ e\ d$ at right angles to $a\ e\ c$, and set on $e\ d$ the divisions e 1, e 2, &c., respectively equal the corresponding lengths 1 a_2, 2b_2, &c., in the side vation. Through the points thus found, with centre e,

draw circular arcs cutting the perpendiculars just drawn in *a*, *b*, *c*, *d*, &c. A curve traced through these points will be the *plan* of the curve formed by the intersection of the cone and cylinder.

In side elevation make $a\ a_2$, $b\ b_2$, &c., respectively equal to $a\ a_2$, $b\ b_2$ $c\ c_2$, &c., in plan; and a line drawn through the points *a*, *b*, *c*, *d*, &c., will be the side elevation of the curve of intersection.

The development of the curve of intersection on the surface of the cone is found by transferring the distances $e\,m$, $e\,1$, $e\,2$, &c., on the slant side of the cone, in the side elevation, to the corresponding line in the development, and through the points thus formed drawing with the centre *e*, circular arcs, *a q*, *b p*, *c o*, &c., respectively equal to the corresponding arcs, *a q*, *b p*, &c., in plan.

To find the development of the surface of the cylinder draw the straight line $m_1\ m_1$, equal to the circumference of the right section of the cylinder, and divide it into the same number of equal divisions. At the points a_1, b_1, c_1, &c., thus found, erect perpendiculars, $a_1\ a$, $b_1\ b$, $c_1\ c$, &c., respectively equal to the corresponding lines, $a_1\ a$, $b_1\ b$, &c., in the side elevation. The curved line *m a b c*, &c., drawn through the points thus found, will be the development of the curve of intersection in the surface of the cylinder.

PROJECTIONS OF THE CYLINDER.

119. The projections and development of the cylinder have been already described in arts. 101 and 106; but as it is of great importance that the subject should be thoroughly understood, we return to it again, for the purpose of explaining the nature of spiral lines, and the manner of projecting them.

20. In the diagram (fig. 43, plate 5) the right cylin- is supposed to be in a horizontal position, in order t the application of the projections here described he construction of vaults and arches may be more rly understood.

he elevations of the ends of the right cylinder, C D, fig. 43, plate 5, will be circles exactly coin- ng with the square sections. The plan will be a tangle, and the development, B A B C D C, will also a rectangle, whose width, B A B, = circumference he circle formed by the square section.

21. If the cylinder be cut obliquely by a plane face, as shown by the line E B on plan, the resulting tion will be an ellipse, whose major axis = E B, and ose minor axis = diameter of the cylinder.

he development of the curve of the oblique section ound as follows:—Divide the circumference of the are section into any convenient number of parts, as een. Divide the width of the development in the ne manner as shown at 1, 2, 3, &c. Transfer the isions on one-half of the square section to the plan, as wn at C 1 2 3 4 5 6 7 D. Through the points thus nd, draw lines parallel to the axis of the cylinder ting the line B E at *a b c d e f g*. Through the points 3 4 5, &c., in the development, draw lines 1 *a*, 2 *b*, &c., parallel to the side of the cylinder, and re- ctively equal to the lines 1 *a*, 2 *b*, 3 *c*, &c., in plan. urve drawn through the points *a b c d*, &c., will be development of the curve of the oblique section.

22. If we draw on the development any straight in an oblique direction, as C E B, this line, when pped round the surface of the cylinder, will form a al line whose inclination to the base of the latter be uniform throughout its whole extent.

123. In building cylindrical arches on an oblique plan in spiral courses, the lines of the coursing joints are called *coursing spirals;* and those drawn perpendicular to them, for the purpose of determining the position of the heading joints, are called *heading spirals.*

124. Let it be required to project a spiral, as C E B, which makes one revolution in the length C B. Having divided the plan and development, to correspond with the divisions on the circumference of the square section as before described, join C B, and this line will be the development of the spiral C E B.

Make the lengths 1 a_2, 2 b_2, 3 c_2, &c., on plan, respectively equal to the lengths 1 a_2, 2 b_2, 3 c_2, &c. on the development. A curved line drawn through the points a_2, b_2, &c., will be the horizontal projection of the spiral C E B.

125. *In the Elevation of the Face of an oblique cylindrical Arch, to draw the spiral Lines in the Soffit, as, for example, the heading Spiral* B a_1 b_1 c_1 d e_1 f_1 g_1 E *in the Plan.*—The plan and development of the spiral are found as above described. Draw E B = E B in plan. Bisect it in d_1, and on E d_1 B, with d_1 as a centre, draw the square section of the arch, divide it into eight equal parts, as before done to obtain the development of the cylinder, and through the opposite divisions, 1 7, 2 6, 3 5, draw lines parallel to E B. From the points a_1, b_1, c_1, &c., in plan, let fall perpendiculars on E B, and transfer the points thus formed to E B in elevation. Erect perpendiculars at these points, cutting the lines 1 7, 2 6, 3 5, in a_1, b_1, c_1, &c., and a line drawn through these points will be the elevation of the spiral projected on a plane parallel to that of the face of the arch. The elevation of a coursing spiral is obtained in the same way.

126. *To draw an oblique semi-cylindrical Arch with*

urved Face (fig. 44, plate 6).—Draw the square section l divide the soffit into any convenient number of equal ts, as eight. Transfer these divisions to the plan, as own in the diagram; and through the points 1, 2, 3, 4, 5, 7, draw lines parallel to the springing lines of the h $a\,a_1$, $i\,i_1$, cutting the face of the arch at $b\ c\ d\ e\ f\ g\ h$.

To develop the soffit, draw $i_1\ a_1$ = the length of the fit on the square section; and, having divided it into same number of equal parts, set up the perpendiculars, $i_1\ i$, $7\ h$, $6\ g$, $5\ f$, &c., respectively equal to $i_1\ i$, , $6\ g$, &c., on plan. A curve drawn through $i\ h\ g\ f\ e$, ., will be the development of the front line of the fit.

To develop the face, draw $a\ i = a\ i$ in plan, and set off , 1 2, 2 3, &c., respectively equal to $a\ b$, $b\ c$, $c\ d$, &c. ect the perpendiculars 1 b, 2 c, 3 d, &c., respectively ıal to the heights 1 b_1, 2 c_1, 3 d_1 in the square section, d a curve drawn through $a\ b\ c\ d\ e$, &c., will be the velopment of the face of the arch.

Cases similar to that here given are not of frequent currence, but they are sometimes unavoidable, as in ilding a skew culvert in the face of a curved wingll.

127. *Intersections of the cylindrical Surfaces.*—The ıder who has carefully studied the preceding pages ll find little difficulty in applying the principles of ojection to the delineation of the intersections of cydrical surfaces. We shall therefore, in the following examples of the intersections of vaulting surfaces, ıit the detailed description of the manner of conucting the several projections and developments, ısting that the diagrams themselves will be found fficiently explanatory.

128. Fig. 45, plate 6, represents the intersection of

two semi-cylindrical vaults of equal span. Each groin will form a straight line on plan, and its profile will be a semi-ellipse, whose semi-axis major = C E, and whose semi-axis minor = D B.

129. Fig. 2, plate 1, represents the intersection of a semi-cylindrical vault, A B C, with a cross vault, A_1 B_1 C of smaller span, but of the same height, the groins being in vertical planes, and forming straight lines in the plan. In this case the square section of the smaller vault will be a semi-ellipse whose minor axis = A_1 C, and whose semi-axis major = D B. The profile of the groins will be elliptical, as in the last instance.

130. Fig. 3, plate 1, shows a method commonly adopted in the infancy of vaulting for constructing intersecting vaults of the same height, but of different spans. The smaller vault, as well as the larger one, was usually a semi-cylinder, and its springing was raised above that of the larger vault just so much as was required to make the crowns of the two vaults coincide.

By this awkward expedient, the necessity for which appears to have arisen from the builder's ignorance of the principles of projection, the groins are made to lie in twisted planes, and form waving lines on the plan. The groins themselves, when viewed from below, appear crippled, and have an unsightly appearance.

131. In fig. 46, plate 6, is shown the intersection of two vaults of different spans, springing from the same level. The groin thus produced is called a *Welsh groin*.

PROJECTIONS OF THE SPHERE.

132. We have already stated that the plan and elevation of a sphere will always be a circle; and that every plane section of a sphere will be a circle, the

jection of which will be a circle, an ellipse, or a ight line, according to its position. It is therefore iecessary to say anything further here, either as to projections or development of the sphere, beyond erring the reader to articles 101, 102, and 107, and igures 34 and 37, plate 4, the latter of which illus-es the approximate development of a sphere, by con-ering it as a series of conical zones.

33. Fig. 47, plate 6, represents the intersection of a nispherical dome, with four semi-cylindrical vaults, l will be understood without any verbal description.

34. If the reader has made himself master of the blems given in this section, he will have no difficulty projecting the intersections of any curved surfaces atever, of which the profiles and directions are given. think it therefore unnecessary to swell the bulk of little volume by any further examples, and proceed once to the subject of the Third Section, namely, the lication of masonic projection to the scientific opera-ns of Stonecutting.

SECTION III.

PRACTICAL STONECUTTING.

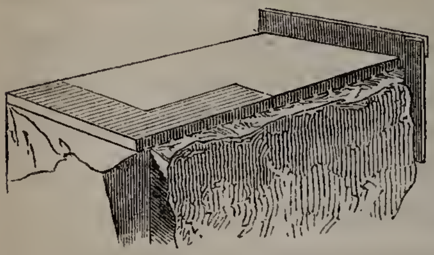
PART I.—GENERAL PRINCIPLES OF STONECUTTING.

FORMATION OF SURFACES.

35. In working a block of stone the workman ins by bringing to a plane surface one of its largest es, which will generally form one of the beds. Its uired shape having been marked on the surface thus med, either with the square or with a templet, chisel-

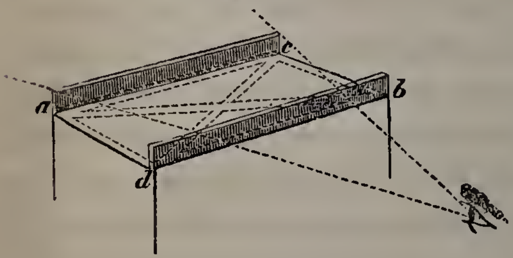
drafts are sunk across the ends of one of the adjacent faces, by means of a square or a bevel, as shown in fig. 48, and this second face is worked between these drafts. The position of a third side is then determined, and its face worked in the same manner, and this process is repeated until the block is brought to its required shape.

Fig 48.



136. *To form a Plane Surface.*—1st, when the surface is of considerable size. Two diagonal drafts, as *a b*, *c d* (fig. 49), are run across the surface and connected by cross drafts, as *a d* *c b*. The superfluous stone is then knocked off between the drafts, until the surface coincides in every part with a straight-edge.—2nd, when the surface is small. In this case a chisel-draft is sunk along one edge of the stone, and a rule with parallel edges placed upon it. The workman then takes a second similar rule, and sinks it in a draft on the opposite edge, until the upper edges of the rules are out of winding, when the two drafts will be in the same plane, and the face may be dressed between the drafts.

Fig. 49.

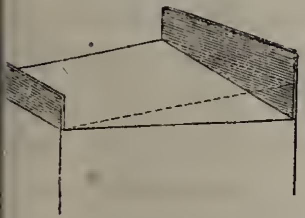


137. *To form a winding Surface.*—For this purpose the workman prepares two rules, one with parallel, the other with divergent, edges; the amount of divergence depending on the distance at which they are to be placed

art. Thus rules are sunk into drafts across the ends the stone, until their upper edges are out of winding. ıe extremities of the drafts are connected by addinal drafts along the sides of the block, the surface of ıich is then knocked off until it coincides throughout th a straight-edge applied in a direction parallel to ıt of the drafts.

The diverging rule is called the *winding-strip*, and rules are called *twisting-rules.* The parallel rule l of course form a rectangle, whilst the form of the erging rule will be that of a triangle with a rectangle added to it. See fig. 50. As the width of the rectangular portion of the rules has nothing to do with the twist, we shall, throughout the following pages, consider the parallel rule as a straight line, and the winding-p as a triangle, which will much simplify the diams.

Fig. 50.



n building oblique bridges with spiral courses, the er are worked so that their winding-beds form porıs of spiral planes; and the accurate determination the *twist* is a problem of great importance.

38. We have already (articles 122 and 124, and 43, plate 5) described the manner of tracing a spiral on the surface of a cylinder.

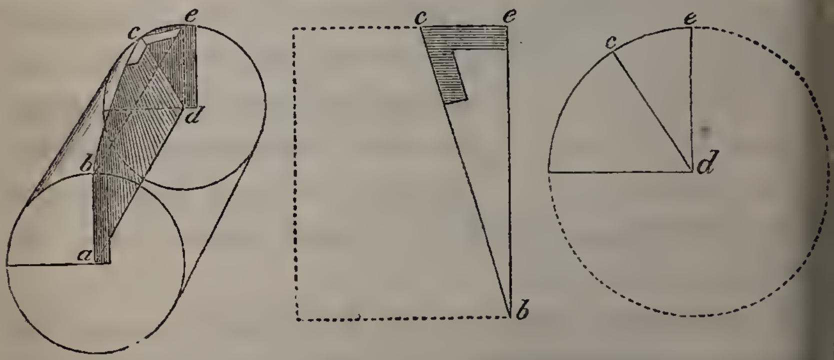
f a cylinder be cut along a spiral line traced upon surface in such a manner that the resulting section everywhere coincide with a straight-edge applied pendicularly to the axis of the cylinder, the surfaces produced are called spiral planes. A familiar mple of a spiral plane whose width is equal to the us of the circumscribing cylinder, is afforded by

the soffit of a cork-screw staircase, such as may be seen in many church towers.

139. *To find the Dimensions of the Winding-Strip for working a Spiral Plane.*—In order that the principle on which the dimensions of the winding-strip are formed may be more clearly understood, we shall first assume the width of the spiral surface to be equal to the radius of the cylinder.

Fig. 51 is the perspective view of a quarter of a cylinder, of which fig. 52 is the development, and fig. 53 the right section.

Fig. 51. *Fig.* 52. *Fig.* 53.



Let $b\ c$, fig. 52, be the development of the spiral $b\ c$ fig. 51. In fig. 53, make the arc $e\ c = e\ c$ in fig. 52 join $d\ c$, and the sector $d\ e\ c$ will represent the winding strip.

In applying the twisting-rules to the stone, they mus be kept in parallel planes at a distance $= a\ d$, an perpendicular to the axis of the cylinder. It will be ob served that the working edges of the rules will diverg from each other, the distance $b\ c$ being greater tha $a\ d$. To keep these edges, therefore, at the proper de gree of divergence, it is convenient to connect the rule with light iron rods, of which the lengths can be readi

tained from the development. If any difficulty is perienced in keeping the side of the winding-strip in lirection perpendicular to the axis of the cylinder, a iall bevel may be used as shown in fig. 51, set to the gle *e c b* in fig. 52.

The twisting-rules should be made as thin as possible, d the working edges should be rounded, so that they ıy rest on the stone in the middle of their thickness ly, as it would otherwise be necessary to form them a winding surface.

The drafts *a b*, *d c*, fig. 51, having been sunk to the oper twist, the surface *a b c d* will be dressed off so to coincide everywhere with a straight-edge applied the two drafts with its ends equidistant from the ints *a* and *d*.

140. If a straight line be drawn between any two ints in the circumference of a spiral plane, it will not incide with the spiral surface, and will only meet the ter in the extreme points lying in the circumference d at a point midway between them. It should be early understood, therefore, that the process just deribed does not produce a spiral surface, although the proximation is so near in ordinary cases that the fference is scarcely appreciable, the distance between e twisting-rules being made so small, that for practical ırposes the spiral *b c* may be considered as a straight ıe.

141. Let us now take the case of a spiral surface, ıose width is less than the radius of the circumscribing linder.

Let figs. 54, 55, and 56, be respectively the perspecve view, the development, and the right section of the ıarter cylinder, the axial length *b f* being the distance which the twisting-rules are to be applied.

Fig. 54.

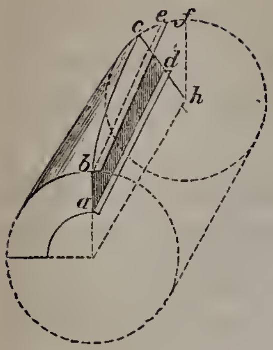


Fig. 55.

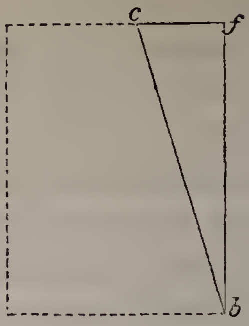
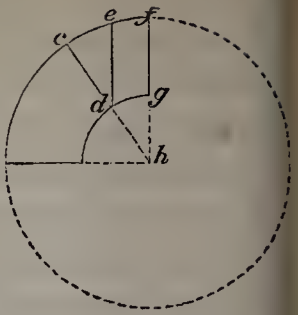


Fig. 56.



Let *b c*, fig. 55, be the development of the spiral *b c*, fig. 54: in fig. 56, make the arc *f c* = *f c* in fig. 55.—Join *c h*, and from *d*, the point in which *c h* cuts the arch *g d*, draw *d e* parallel to *h f*. Then *d e c* represents the winding-strip. The mode of applying the twisting-rules is precisely the same as described in art. 139; in fact these rules are merely portions of the larger rules shown in fig. 51.

142. Instead of applying the twisting-rules *across* the ends of the stone as above described, some masons prefer placing them in the *length* of the bed. In this case the dimensions of the winding-strip are obtained on the assumption that it is a continuation of the *extradosal* cylindrical surface.

The working edges of the rules will be same distance apart at each end, whilst their outer edges will be divergent.

Fig. 57.

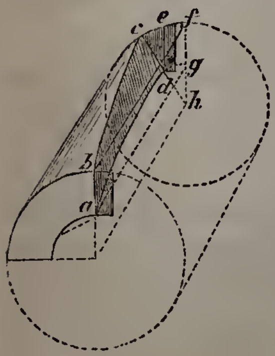
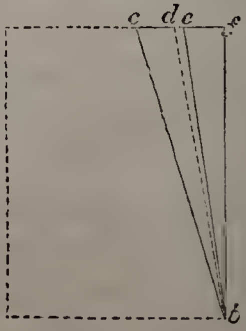


Fig. 58.



Let figs. 56, 57, and 58 be respectively the right section, the perspective view, and the

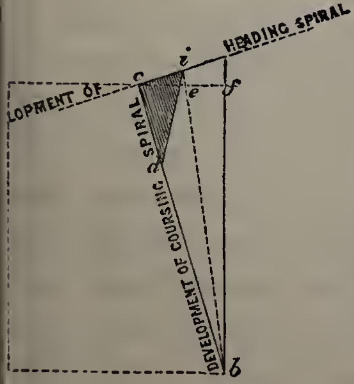
velopment, as before. Find $c\ e\ d$, fig. 56, as before. the development, make $f\ e = f\ e$, fig. 56; join $b\ e$, en $b\ e\ c$ is the winding-strip.

We have already said that when the twisting-rules to be applied to the *length* of the stone, the winding-ip is assumed to be a continuation of the extradosal lindrical surface. But as the wide end of the winding-ip in reality is the chord of the arc $c\ e$, and as the rking edges of the rules do not coincide with the ex-dosal and intradosal spirals, but are chords to them; dimensions given by the process above described, uld be subject to a slight correction, were they required be mathematically correct. Practically, however, both spirals and the arc $c\ e$ may be considered as straight es, and the correction is therefore unnecessary.

The length of the working edge of the parallel rule l be found by setting off on the development $= g\ d$, fig. 56, and joining $d\ b$, which will be the gth required.

143. There is yet a third way of obtaining the wind-;-strip, which is to consider it as portion of a spiral ding plane. In the development, fig. 59, draw $c\ i$ per-ndicular to $c\ b$, and meeting $b\ e$ produced in i; set off $c\ d = c\ d$, fig. 56, and join $i\ d$, then $d\ i\ c$ represents the winding-strip. This, again, is only an approximation, as the top of the winding-strip should not be a straight line, but a spiral, of which $c\ i$ is the development. This correction, however, is too trifling to be worth notice.

Fig. 59.



The working edges of

these twisting-rules will be applied with the same degree of divergence as those described in art. 141, but their outer edges will also be divergent, not parallel. The top of the winding-strip will form a right angle with the extradosal spiral.

144. Of the three methods above described, the first is the most accurate, as the dimensions of the winding-strip are obtained correctly, whilst in the other two the dimensions obtained are merely approximations, to which corrections must be applied if very great accuracy be required. The last method is, however, most convenient for the workman, who will always, unless otherwise directed, apply the winding-strip so that its wide end shall be square to the surface of the stone.

SOLID ANGLES.

145. Solid angles are those formed by the meeting of three or more faces in one point, and require for their execution two kinds of bevels, viz.:—

1. The face bevel, containing the angle formed by the meeting of two arrises bounding one of the faces.

2. The dihedral bevel, containing the angle formed by the intersection of two adjacent faces.

146. The angles of the faces, or, as we shall term them, the *plane* angles, are best worked from a thin templet applied on the face of the stone, as shown at *u B v* (fig. 60).

In making a bevel to work a *dihedral*, the sides of the bevel are set to the angle that would be formed by the intersection of a plane perpendicular to the common arris; and in applying the bevel to the stone it must on each face be kept square to this line, as

own at r B j (fig. 60), making A B r, A B j, each right gles.

147. The solid angle occurring most frequently in actice, is that formed by the junction of *three* plane es, to which the name of trihedral has been given. trihedral has three plane angles and three dihedrals, which six, any three being given the remaining three also given, and may be obtained, all of them, by culation, some of them by construction. We shall re, however, consider only how in those cases which of most common occurrence they may be obtained construction, viz.:—

1st. When the three plane angles are given.

2nd. When two plane angles and the included dihe- al are given.

3rd. When one plane angle and the two adjacent hedrals are given.

148. In each of these cases the remaining angles can found by a simple geometrical construction; and as lines to be drawn are the same in each case, it will ve repetition to describe the whole of the figure in e first instance.

Fig. 60.

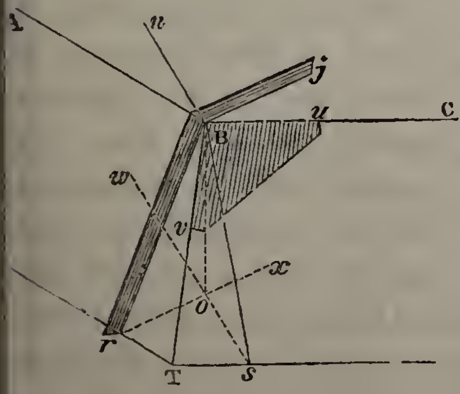


Fig. 60 is a perspective view of a trihedral of which the faces A B T, C B T, are supposed to be bounded by a plane, r T s, parallel to the face A B C, at a distance, B o, measured at right angles to the face, A B C. The di-

hedral angles, r B j, s B n, adjacent to the face, A B C, are shown as formed by the intersections of the cutting planes, x r B j, w s B n, perpendicular respectively to the arrises A B, B C.

Figs. 61 and 62 are developments of the trihedral (the plane angles being in the one case all obtuse, in the other all acute), the plane angles h B A, A B C, C B e, corresponding to the angles T B A, A B C, C B T, in fig. 60, and the lines B h, B e, being of equal length and corresponding to the arris B T (fig. 60), h i, e f being parallel respectively to A B, B C. Erect the perpendiculars B i, B f; draw e D, h D, respectively, parallel to f B, i B, and meeting each other at D; join B D, and draw D k, D g respectively parallel to A B, B C. Then A B D C will be a plan on a plane of projection parallel to the face A B C, B g being $=$ o s (fig. 60), and B k $=$ o r (fig. 60). Now, in order to project the sections x r B j and w s B n (fig. 60), set off on the lines B A, B C (figs. 61 and 62), equal

Fig. 61.

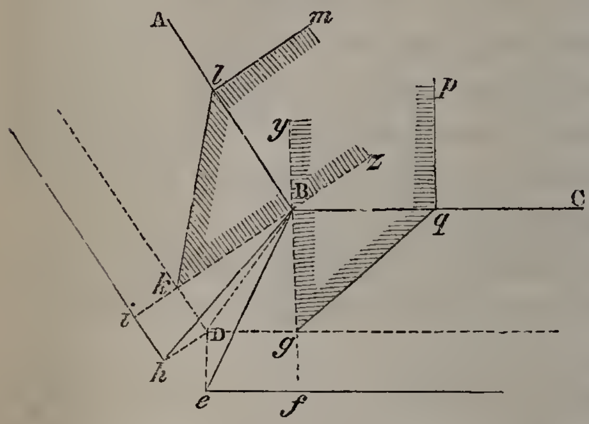
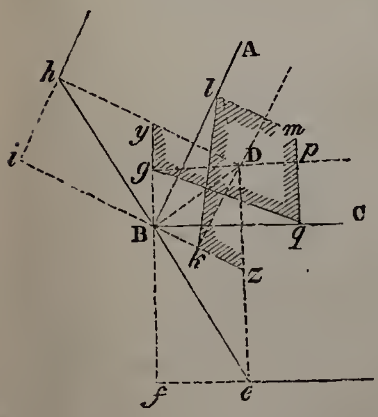


Fig. 62.



stances B l, B q, corresponding to the perpendicular stance B o (fig. 60) of the two parallel planes; erect e perpendiculars $l\ m$, $q\ p$; and join $l\ k$, $q\ g$. If i B, B be produced to any points, $z\ y$, beyond $k\ g$, re-ectively, then $z\ k\ l\ m$, $y\ g\ q\ p$ will be the respective ojections of the sections $x\ r$ B j, $w\ s$ B n, so that $l\ k$, $p\ q\ g$ are equal to j B r, n B s; and $l\ k$, $q\ g$ to r, B s, that is, to B i and B f respectively.

149. In applying this diagram to practice, A B C is vays made one of the given angles, and the per-ndiculars, B i, B f, having been drawn of convenient ıgths, the remainder of the figure is completed either m the plane or the dihedral angles, as the case may ıuire.

150. Case 1. *Given three Plane Angles of a Trihe-ıl, to find the Dihedrals.*—Draw the development d find the point g, as in art. 148. With g as a ıtre, and radius $g\ q$ = B f, describe an are cutting : at q. Join $g\ q$, and draw $q\ p$ perpendicular to B C; ın $g\ q\ p$ will be one of the dihedrals, and the other ɔ may be found in a similar manner.

151. Case 2. *Given two Plane Angles and their luded Dihedral, to find the remaining Angles.*—Let 3 C, e B C, be the given plane angles, and $g\ q\ p$ their luded dihedral angle. Having found the point D, .w D h parallel to B i, and with B as a centre and ius B e, describe an arc cutting D h at h: join B h, l A B h will be the remaining plane angle. The re-ining dihedrals will be found as in art. 150.

152. Case 3. *Given one Plane Angle and two ad-ent Dihedrals, to find the remaining Angles.*—Let 3 C be the given plane angle, and $k\ l\ m$ and $g\ q\ p$ adjacent dihedrals. Make B i, B f respectively

equal to $l\,k$, $q\,g$. Draw D h, D e, $i\,h$, $f\,e$ as described in art. 148, and join B h, B e: then A B h, C B e are the remaining plane angles, and the remaining dihedral can be found as in art. 150.

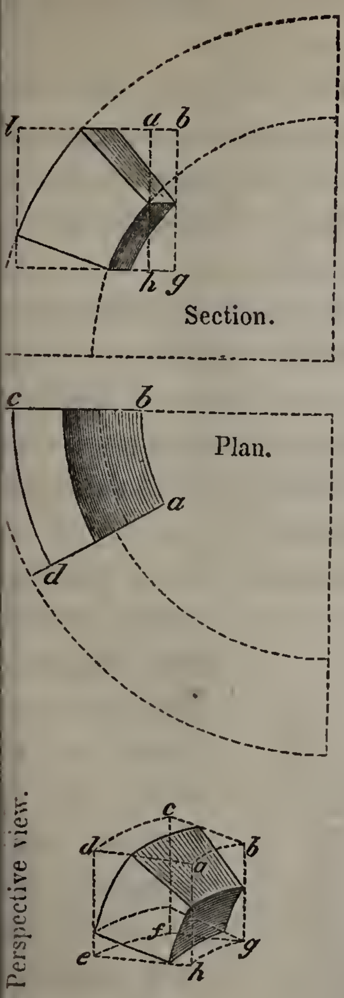
SURFACES OF OPERATION.

153. No difficulty occurs in working a block of stone, of which the faces, beds, and joints are to be either vertical or horizontal planes, as the several dimensions required can be obtained directly from the plan and elevation. Nor is any difficulty introduced if some of the surfaces are cylindrical, as a cylindrical surface can be worked with almost as much facility as a plane; the only difference being that a curved rule is used in one direction and a straight one in the opposite, whilst in the latter case the straight-edge alone is used.

154. If however any of the sides of the block are to be formed into conical, spherical, or spiral surfaces, the matter becomes somewhat complicated, and it is necessary first to bring the stone to a series of planc or cylindrical surfaces on which to apply the bevels and templets required for finishing the work. These preparatory surfaces are called *surfaces of operation*. In cases wherc the blocks are of large size, they are brought to their approximate shape at the quarry, and it is of importance that the quarryman should be enabled to do this in such a manner as to reducc the subsequent labour of the mason as much as possible.

155. The simplest plan is to make the surfaces of operation either horizontal or vertical, by which means the lines required for making the bevels and templets

Fig. 63.



can be taken directly from the plan and section, which are horizontal and vertical projections. Thus, let it be required to work a voussoir of a dome—we may first work the block roughly, so as to form a portion of an upright hollow cylinder, as shown by the dotted lines in fig. 63, and transferring the lines of the plan and section to the surfaces of operation thus formed, the subsequent operations become very simple.

When the stones are small, and stone abundant, this will generally be the best mode of proceeding; but, with large blocks, the waste of material and labour would be very serious, and it is necessary to use such methods as will enable us to economize the material as much as possible.

PART II.—APPLICATION OF PRINCIPLES TO PARTICULAR CONSTRUCTIONS.

156. Having now explained the general principles stonecutting, we proceed to show their application some few particular constructions, each of which may regarded as the type of a class to which the same

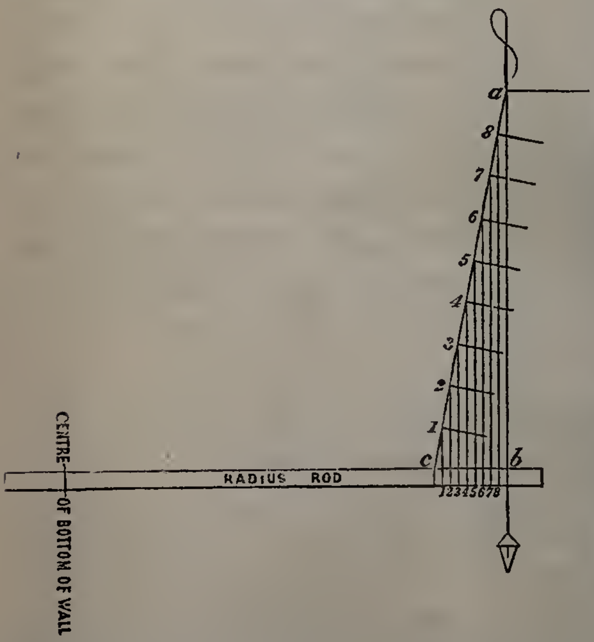
rules are applicable, with such trifling modifications as the circumstances of each individual case may render desirable.

157. *Curved Wing-Walls.*—To execute a wall with a straight batter on a curved plan requires much care and attention, and a considerable number of templets for the proper working of the conical beds of the courses, and for obtaining the twist of the coping.

We have already described in detail the manner of constructing the several projections required in designing a conical wall, and therefore need not say anything further on the subject in this place, but will proceed at once to describe the manner of obtaining the necessary templets, and of working the stone.

158. *Arrangement of the Courses.*—On a platform draw a straight line equal to the vertical height of the wall at its highest point; calculate how much the wall will batter in this height, and set off the distance at right angles to the first line, as shown in fig. 64, where *a b* is the vertical height of the wall, and *b c* the amount of batter. Draw

Fig. 64.



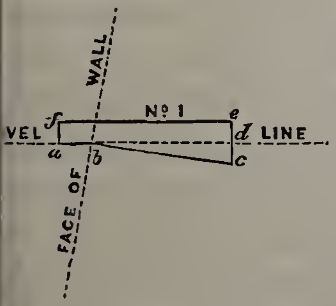
e face line $a\ c$, and divide it into the intended num-
r of courses.

When the stone provided for the work runs of various icknesses, measure the thickest and the thinnest blocks d gauge the bottom and top courses accordingly; set these dimensions on the face line $a\ c$, and arrange e intermediate courses as described in art. 78, Section . Number the bed-joints as shown in the figure, ginning from the bottom of the wall.

Provide a rod, and mark on it the radius of each bed-nt, numbering each joint in succession to correspond th the numbers on the line $a\ c$.

159. *To work the top Bed.**—The beds of the courses a battering wall are made to dip at right angles to e face, whilst their front arrises lie in horizontal ines. The first operation therefore will be to form a rizontal surface of operation on which to apply a rved templet, cut to the radius of the front arris.

Fig. 65.



Make a bevel, as shown in fig. 65, so that the angle $a\ b\ c$ shall be the dip of the bed. The length of $b\ c$ will be regulated by the width of the stones to be worked; that of $a\ b$ by their length—the width, $d\ e$, of the rectangular portion, $a\ d\ e\ f$,

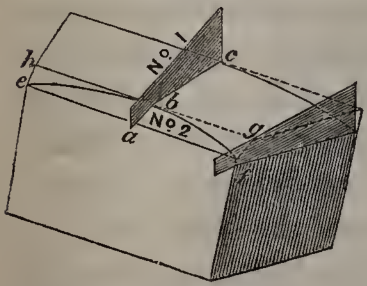
* We are not aware that this method has been previously published. method most commonly in use is the first of the two methods described Mr. Peter Nicholson in his 'Practical Masonry,' etc. Mr. Nichol-'s rule is a very excellent one, but the construction of the hyperbolic iplet for obtaining the wind of the bed is too complicated to be under-od by an ordinary workman. In the rule here given, the lines of templets are those of the work itself, and can be taken directly from plan and section.

is of little consequence; 3 inches is a convenient dimension. Call this bevel No. 1. It will apply to the whole of the courses.

Make a curved templet to the radius of the front arris, as set out on the rod described in art. 157. The length of this templet must be a little more than that of the longest stone in the course. Call this templet No. 2. Each bed-joint requires a separate templet, but the same templet will work the *top* bed of one course and the *bottom* bed of that next above it

With No. 1 sink a shaft *a b c* (fig. 66) across the centre of the length of the block, so that *a b* is equal to the versed sine of the curve of the front arris. Through *b* draw *h b g*, perpendicular to *b c*, and knock off the front edge of the block, so as to form the horizontal surface of operation *e a f g b h*. On this surface apply No. 2, and draw the curve of the front arris *e b f*, keeping the curve perpendicular to *b c*. Make a duplicate of No. 1, and with these two rules bring the top bed to its proper wind. To do this, one rule must be placed at *b c*, and the other on successive portions of the surface, the rule being kept square to the curved line, *e b f*, and placed so that the point *b* coincides with it. The second rule must then be sunk till the upper edges of both rules are out of winding. (See fig. 66.)

Fig. 66.



On the bed thus worked draw a line square to the front arris as shown in fig. 67, and make a flexible templet to the angle *e b c*. This templet when laid flat will be a portion of the development of the conical surface of the bed, and when bent round the stone will give

Fig. 67.

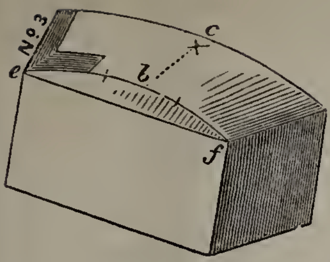
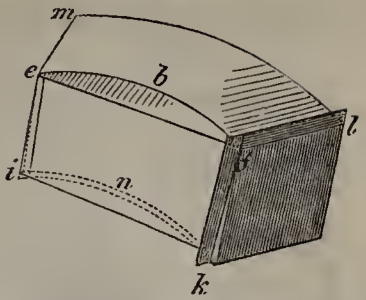


Fig. 68.



he direction of the joint. Call this templet No. 3. Each course requires two templets, but the same templet will work the *top* bed of one course and the *bottom* bed of that next above it. Gauge the top bed to a regular width, and mark off the radiating ends with No. 3. The stone is now brought to the state shown in fig. 68.

160. *To work the Face.*—With a common square applied at the ends of the top bed, sink a draft at each extremity of the face as shown in fig. 68. On these drafts mark the thickness of the course as shown at *i k*. Take No. 2, corresponding to the front arris of the bottom bed, and sink the draft *i n k*—keeping the templet so that $b\ n = e\ i$, the thickness of the course. Work the face between the top and bottom drafts with a straight-edge. Gauge the arris line *i n k* parallel to *e b f*. Draw a line *b n* (fig. 69) square to the top arris, and make a flexible templet to the angle *e b n*. This templet when laid flat will be a portion of the development of the conical face of the wall, and, when bent into the curved face, will give the direction of the upright joint in the face. Call this templet No. 4. A separate templet will be required for each course. Complete the working of the face by marking off the face-joints *e i*, *f k*, with No. 4, as shown in fig. 69.

161. *To work the Ends.*—The ends of the stones will

be vertical planes, and are therefore worked with a straight-edge applied to the arris lines, *l f*, *f k* and *m e*, *e i*, fig. 69.

Fig. 69.

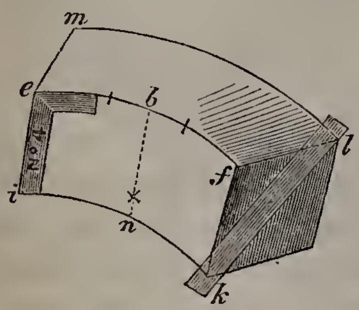
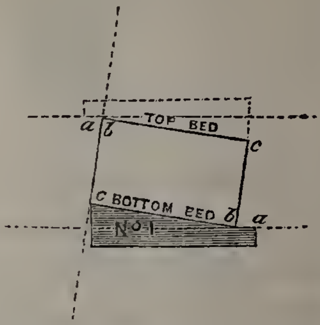


Fig. 70.



162. *To work the bottom Bed.*—This is done with No. 1 and its duplicate, simply reversing the rules, end for end, as shown in fig. 70, keeping the point *c* on the arris *i n k*. The top bed is round, and is worked from the centre to the ends. The bottom bed is hollow and is worked from the ends to the centre.

163. *To build the Wall.*—Set up an iron rod at the centre of the cone, and steady it as may be most convenient (see fig. 71, plate 7; in which however the stays are omitted, to avoid confusing the drawing).

Provide two battering rules, on which mark the bed-joints and fix them very accurately at the extremities of the wall. Then, as each course is laid, try its correctness with the rod described in art. 158, or with a stout measuring tape, of which the ring is passed round the iron rod at the centre of the cone.

These precautions are especially necessary in building curved walls either in brick or in rubble, as without being able to refer to a centre it is very difficult to keep the courses to the proper curve. In building an ashlar wall, the stones being previously brought to the curvature of the face, this difficulty is much lessened; but

; appearance of the coping depends so completely the accuracy with which the work is carried on, that ; use of the centre rod cannot well be dispensed with ;hout a risk of the coping being slightly crippled.

164. *To form the Top of the Wall to receive the ping.*—Shift the rod to *n*, fig. 72. String two lines the plane of the front edge of the top of the wall, as own at *n b*, *n b*, figs. 71 and 72, plate 7. On a platm strike out a quarter ellipse, with semi-axis major $= n\,b$, and semi-axis minor $= q\,n$. Make a templet to s curve, in any convenient number of pieces, and call s templet No. 5. Beginning at *q*, fig. 72, place No. gainst the face of the wall, piece by piece, keeping it of winding with *n b*, *n b*, and draw the line of the nt arris on the top stones, which will have been carl a little above this line. The top of the wall must n be dressed off to this line, keeping the surface level he direction of the centre rod, and it will then be dy to receive the coping.

65. *To work the Coping.*—Divide the front edge of wall into the number of stones which the coping is contain, and square the joints across from the face. it be required to work the stone No. 3, fig. 72—n a point *b* in the front of the wall, corresponding to centre of the stone, draw two lines perpendicular to arris, viz. *a b* on No. 5, and *b c* on the top of the l. Make a bevel to this angle, and call it No. 6. A arate bevel will be required for each coping-stone. n working the stone it is convenient to begin with top surface. The block being roughly scappled to shape; with No. 6 sink a draft, *a b c*, across the tre of the top surface, as shown in fig. 73, plate 7, form a surface of operation, *e a f g b h*, as described rt. 159; the only difference being that, in the present

case, the surface of operation is not horizontal, but lies in the plane *q n b*, fig. 72. On this surface apply No. 5, by which draw the front edge, *e b f*. The dimensions of the twisting-rules required for working the top surface are found by actual measurement from the wall itself. The number of twisting-rules required for each stone will vary according to the degree of twist, which increases from the foot of the wall upwards.* These twisting-rules must be applied in a direction radiating from the face-line, and the workman must commence at the centre of the stone, on the draft *b c*, and work each way to the ends.

The top surface having been worked to the proper twist, the radiating joint lines are marked with a bevel; the angles being taken from the lines previously marked on the top of the wall.

The width of the top of the stone is then gauged parallel with the front line, and the fronts and backs worked. The ends should be left rough until the whole of the coping is worked, in order to ensure an accurate fit.

In applying the square to work the front face, it should be placed so that a plumb-line suspended from any part of the front edge shall coincide with the face. If the square be applied *perpendicular* to the arris, the bottom edge of the coping will appear underset, which has a wretched effect.†

The front and back having been worked, the stone is

* It must be remembered, that the top and bottom arrises of the coping do not lie in parallel planes, as explained in art. 117. The difference in the twist at the top and bottom beds arising from this cause is scarcely appreciable; but it may be allowed for in taking the twist from the top of the wall, when the curve is sufficiently sharp to make this necessary.

† Some persons prefer to make the front of the coping battering: this is simply a matter of taste.

ged to its proper thickness on each side, and the tom bed can be worked with a straight-edge applied ween these lines.

66. We have described the front of the coping to worked with No. 5, and this would be perfectly rect were the coping set flush with the face of the l. But, as it is always overset to a slight extent, two inches, it is evident that the front of the coping st be made to curve a little quicker than the front he wall. In ordinary cases, the difference between se two curves is not perceptible in the length of a ne, but when the radius of curvature is very small, templets will be required, one to work the top of wall, and the other to work the front of the coping.

67. There are very many ways in which the twisted ing of a wing-wall may be worked; but the fore-ng method appears to us the simplest, and that uiring fewest templets. As each stone requires a se-ate bevel, face-mould, and twisting-rules, the trouble making the templets adds greatly to the cost of king the stone, and the last-named consideration herefore one of great importance.

68. Walls are sometimes built on elliptical plans, this should always be avoided if possible, as the king of the stone is a very complicated process.

DOMES.

69. The foregoing rules apply with trifling modifica-ns to the execution of domes, spherical niches, and vaults, and generally to all constructions in which beds of the courses form conical surfaces, and of ch the joints lie in vertical planes. A single example suffice to show the nature of these modifications.

Let it be required to work the voussoir *a b c d e f g*, fig. 74, plate 7, of a hemispherical dome. The top bed in this case is hollow, and the bottom bed rounded, therefore begin with the latter. Obtain the front arris, and work the bed as in art. 159. Work the face, *a d e f*, so as to form a conical surface of operation, as in art. 160; except that the chisel drafts at the ends of the face will be sunk with a *bevel* set to the angle *a d c*, instead of a common square being used. Work the ends as described in art. 161. Obtain the arris *a f*, and work the top bed as described in art. 162; except that, as the inclinations of the top and bottom beds are not the same, there must be as many sets of winding rules as there are courses. Lastly, work the conical surface of operation to the proper curve, with a curved rule, as shown in the figure.

ARCHES.

170. The construction of either circular or elliptical arches, of which the abutments are square with the face, offers but little difficulty.

As the depth of the arch-stones is generally greater than their thickness, the workman commences by working one of the beds. This being done, the ends are squared, and their exact shape marked from a templet. The opposite bed is now worked to the lines thus found. Lastly, drafts are sunk at each end of the soffit to the curves previously marked, and the soffit is dressed off to coincide with a straight-edge applied between the drafts in the length of the stone. This will be understood by inspection of fig. 75, plate 7.

Another method is to work the soffit from the bed first formed, by means of an arch-square or curved bevel, as shown in fig. 76, plate 7. One bed and the

ﬁt being worked, the other bed is worked from the ﬁt in the same way. This method dispenses with the ;essity of squaring the ends before working the soffit, ich is sometimes an advantage.

n both these methods the straight-edge is used for ing the surface between the chisel-drafts at the ls of the curved soffit; but in the first method these fts are got by applying a templet on the squared s, and in the second by means of the arch-square.

71. *Oblique Arches.*—We have in the first section his volume described the different methods in which ique arches may be constructed. In the following es, therefore, we propose to speak only of cylindrical ıes built in spiral courses, of which the beds radiate n the axis of the cylinder. The reader who will take trouble thoroughly to master the rules here laid ɤn, will find no difficulty in executing any other de- ption of arch.

'he construction of a skew arch of which the span, , width of soffit, and angle of skew are given, re- ɾes but very few lines to be drawn for finding the plets and bevels. But it is always desirable, before ımencing operations, to make a large drawing to an ı scale, for the purpose of ascertaining the sizes of stones that will be required, the best manner of .nging the heading joints in the soffit, and such other ;iculars as cannot well be obtained from a small ;ch; and we shall therefore briefly describe the jections and developments that are required for this pose. (See fig. 77, plate 7.)

72. *Plan.*—Draw two lines, *c b*, *d y*, parallel to each ɜr, at a distance, *d e*, corresponding to the square th of the soffit of the arch. Set off the angle of the lge, and draw one impost line, *c d*. Draw the

second impost line parallel to the first, at a distance, *a b*, corresponding to the span of the arch on the square section.

173. *Section.*—With the given span *a b*, and rise *h i*, draw the square section of the arch.

174. *Development.*—Draw a development, *b y k y*, of the soffit of the arch from the data thus obtained. Draw on it the development of a heading spiral, passing through the extremities of the impost lines in one of the fronts. Divide this line into any convenient number of equal parts, as 13, corresponding with the intended number of stones in each face of the arch; an uneven number being always taken, to allow for a key-stone.

From *k*, the opposite end of the impost line making an acute angle with the face, let fall a perpendicular *k l*, on the heading spiral just drawn, which will represent the development of a coursing joint. If this line pass through one of the divisions on the heading spiral, the design may be proceeded with without any alteration of the dimensions; but this will most probably not be the case. It will then be necessary to adjust the dimensions, so as to make the coursing spiral pass through one of the divisions; which may be done—

1st. By altering the width of the bridge.

2nd. By altering its span.

3rd. By altering the angle of skew; or, lastly, by slight adjustment applied to all these data.

If the dimensions of the arch are unalterably fixed, this first coursing joint must be drawn through the nearest face-joint; but, in this case, as the coursing and heading spirals are not perpendicular to each other, the soffits of the stones will be out of square*, which is very objectionable. In building arches of brick, with stone

* That is, if the stones are worked to form regular bond.

oins, as shown in fig. 78, plate 8, this difficulty is rcely felt, because it is not necessary that the face-nts of the opposite fronts should range with each er; all that is required being that they should coin-e with some joint of the brickwork, so that, in this e, the necessary adjustment can never exceed half thickness of a brick.

The angle made in the development, by the intersec-n of the coursing joints with the impost, is called angle of intrados. The corresponding angle, in a elopment of the extrados, is called the angle of ex-los.

75. *Arrangement of Heading-Joints.*—Divide each ost into as many parts as there are divisions cut off the heading spiral by the coursing joint first drawn, ch, in this example, are five in number; and through divisions on the impost; and on the heading spiral, v the developments of the coursing spirals, which be parallel to and equidistant from each other. ough the divisions on the imposts draw heading als parallel to that first drawn, and arrange the ling joints on these lines and on others parallel to n, so as to form regular bond throughout the whole ie soffit. (See fig. 11, plate 2, art. 39.)

will be seen that, from the heading spirals not g parallel to the face line, the quoin-stones will be ery irregular lengths; and this is particularly con-ous in brick arches with stone quoins, whose ends portions of continuous heading spirals. The best of avoiding this is to draw on the development parallel to the face-lines at distances corresponding e intended lengths of the long and short quoins, to make the end of each quoin a portion of a se-te heading spiral, passing through the intersections

of these lines with the coursing joints, as shown in fig 78, plate 8. Some persons, in building brick arche with stone quoins, make the ends of the latter paralle with the face-line, which is very objectionable, as i throws them out of square with the brickwork, which i offensive to the eye, and makes unsound work.

176. *Skewbacks.*—The next thing to be considere is the arrangement of the joints in the imposts. Th top of each impost must be cut into checks or skew backs to receive the ends of the courses; and, as th beds of the courses are worked to radiate from th centre of the cylinder, the checks will be square to it axis, and to the faces of the abutments, as shown in fig 77. In settling the sizes of the stones forming th imposts, it must be borne in mind that the stone at th obtuse quoin will be wider at the back than at the fron whilst the reverse takes place at the acute quoin; an it is of importance that the latter stones shall be sufficient size to bond into the rest of the work. Th thrust of a properly built skew arch being in a directio parallel to its fronts and not at right angles to th abutment, it will always be desirable to make the join of the masonry square to the fronts, and, therefore, th backs of the impost stones should be cut so as to bor with the rest of the masonry, as shown in fig. 79, plate

The last thing to be attended to in the design is t elevation of the arch, and the arrangement of the cours of the spandrils.

177. *To draw the Elevation.*—The curves of t intrados and of the extrados are both portions of ellips of which the spans are to be taken from the plan and t heights from the section. The positions of the joints the intrados are taken from the divisions on the *face-li* of the development of the intrados. Their position

extrados may be formed by developing the extrados, manner of doing which may require some little ex- nation.

)ince the joints are made to radiate in a direction pendicular to the axis of the cylinder, it follows that axial lengths* of the intradosal and extradosal ·als will be the same (see fig. 77, plate 7); but, as the umference of the extrados is longer than that of intrados, the angles made with the abutments by extradosal spirals will be greater than those made the coursing joints in the soffit; or, in other words, angle of extrados will be greater than the angle ıtrados, and, as a consequence, the extradosal plans he stones will be out of square, as shown in the elopment of extrados, fig. 77. In drawing the ding spirals in the development of the extrados, they not be perpendicular to the coursing spirals, nor they pass through the intersections of the face and ost lines, but they will fall within the face at the ıse, and beyond it at the acute, quoins. This will ully understood by reference to the figure. Divide extreme heading spirals into as many equal parts as heading spirals of the intrados, and through these sions draw the developments of the extradosal cours- joints. Transfer the divisions on the *face*-line of extrados to the curve of the extrados in elevation, draw in the face-joints, between the points thus rmined in the extrados and intrados. In strictness, face-joints are not straight lines, but curves; as y intersection of a plane with a spiral surface will curved line, except when the plane of intersection ɛrpendicular to the axis of the cylinder; but, unless

* By axial length is here meant the distance measured on the axis of a ler, corresponding to an entire revolution of a spiral.

the bridge is very much on the skew, the curvature is not worth noticing in the drawings, as its omission does not in any way affect the work.

178. *Focal Eccentricity.*—It was first pointed out by Mr. Buck,* that the face joints of an oblique arch of equal thickness from the springing to the crown have a remarkable property, viz. that their chords all radiate from a point below the axis of the cylinder, the distance increasing with the angle of obliquity; and he gives in his work the following simple rule for ascertaining this distance, which he calls the focal eccentricity (see the lower part of fig. 77, plate 7). Draw $a\,b =$ radius of extrados, and $b\,c$ perpendicular to it, making the angle $a\,c\,b =$ angle of skew; draw $c\,d$ perpendicular to $b\,c$, making the angle $c\,b\,d =$ angle of intrados; then $c\,d$ is the focal eccentricity. For the demonstration of this rule we refer the reader to Mr. Buck's work. By taking advantage of this property of the face-joints, we can draw the elevation without the trouble of making a development of the extrados, which saves much time.

179. *Spandrils.*—The face-joints having been drawn, the last thing to be done is to arrange the lengths of the quoin stones, and the heights of the spandril courses. This is sometimes troublesome to manage, as it is necessary for the appearance of the work that the heights of the spandril courses should diminish regularly from the springing to the crown, and the lengths of the quoins must be adjusted so as to effect this. If the elevation is carefully drawn to an inch scale, the lengths of the quoins can be obtained from it with sufficient accuracy without drawing a full-sized elevation; which is an expensive operation, as it requires a large extent of platform.

* 'A Practical and Theoretical Essay on Oblique Bridges,' by the late George Watson Buck. (See Chap. II.)

We now proceed to describe the manner of finding e bevels and templets for the execution of the work.

180. In fig. 80, plate 8, let

$\angle\, d\,c\,b$ = angle of skew.
$a\,b$ = span on square.
$h\,i$ = versed sine of arch.
$d\,e$ = width of soffit on the square.
$a\,x$ = radius of intrados.
$c\,b$ = oblique span.
$c\,d$ = length of impost.
$b\,f$ = development of square section.
$b\,g$ = development of heading spiral.
$\angle\, g\,k\,l$ = angle of intrados.

Of these data, the four first are known, and the others ust be found from them, either by geometrical con-ruction on a platform, or by calculation; the latter plan ;ing the most correct, the quickest, and the cheapest.

181. *Radius.* $a\,x = \dfrac{a\,h^2 + i\,h^2}{2\,i\,h}$ see art. 83.

182. *Oblique Span.* $c\,b = a\,b \times cosec \angle\, d\,c\,b$.

183. *Length of Impost.* $c\,d = d\,e \times cosec \angle\, d\,c\,b$.

184. *Development of Square Section.*—The natural ne of the angle $a\,x\,h = \dfrac{a\,h}{a\,x}$. Look in a table of na-:ral sines for this number, and call the corresponding ımber of degrees n; then $b\,f = a\,i\,b = 2\,n \times a\,x \times$ 17453 (as in art. 88).

185. *Development of Heading Spiral.*—First $f\,g = a\,c$: $a\,b \times$ cotang $\angle\, d\,c\,b$.

Then $b\,g = \sqrt{b f^2 + f g^2}$ = development of heading)iral.

186. *Angle of Intrados.* $\dfrac{f\,g}{b\,f}$ = sine of $\angle\, f\,b\,g$ = ne of $\angle\, g\,k\,l$.

187. The above calculations are best performed by the aid of a table of natural sines, secants, and tangents, without using logarithms, and may be made with a table of natural sines only; but the operation is somewhat tedious in the latter case, as it involves dividing by the sine of the angle of skew, which is very troublesome, as the sine should not be taken to less than six places of decimals :—

$$\text{Thus, the oblique span, } b = \frac{a\,b}{\sin \angle\, d\,c\,b}$$

$$\text{and the impost length } d\,c = \frac{e\,d}{\sin \angle\, d\,c\,b.}$$

188. These dimensions having been calculated, the lengths of the imposts and of the development of the heading spiral must be set out very exactly on long rods, and divided into the number of equal divisions previously determined on. The divisions of the impost rod will give the exact length of the checks to be cut on the springers, and the divisions on the other rod will show the exact width of the courses.

189. *Templets for the Skew-backs.*—On a sheet of zinc, draw two lines at right angles to each other, as $a\,b$, $b\,c$, fig. 81, plate 8; set off $b\,c$ = width of a course on the soffit, and $b\,a = b\,c \times \cot \angle$ of intrados. Join $a\,c$. Then the triangle $a\,b\,c$ will be the form of the templet for the impost checks in the soffit, and $a\,c$ should exactly agree with the length of check previously ascertained. From b let fall on $a\,c$ the perpendicular $b\,d$. On a platform draw a straight line $a\,b\,c$, fig. 82, plate 8, making $a\,b$ = radius of intrados, and $b\,c$ = thickness of arch at springing. With centre a, and radius $a\,b$, draw the arc $b\,e = b\,d$, fig. 81. Through e draw $a\,e\,d$, making $e\,d = b\,c$. With centre a, and radius $a\,c$, draw $c\,d$,

cutting $a\ e\ d$ in d. In fig. 81, produce $b\ d$ to e, making $b\ e = d\ c$ in fig. 82; join $a\ e, e\ c$; then $a\ e\ c$ is the form of the templet for the impost checks on the extrados.

190. In working the springers, they are first brought into a cylindrical form, and divided into the proper number of checks by the impost rod. The templets are then applied on the intrados and extrados, and their profiles marked on the stone, which is then cut away to these lines.

191. *Twisting-Rules.*—On the platform set out the angle of intrados, as $g\ k\ l$, fig. 80, plate 8, and let $k\ m$ be the axial distance at which the parallel ends of the twisting-rules are to be applied. Draw $m\ n$ perpendicular to $k\ g$; $n\ k$ will be in the distance between the rules on the intrados. On the platform with radius of intrados, x, fig. 83, plate 8, draw $n\ m = n\ m$ in fig. 80. Draw $m\ n\ p$ and $x\ n\ o$, and the concentric arc $o\ p$, making $o\ n = m\ p$ = thickness of arch. On $n\ m$ produced, fig. 8, set off $m\ o = p\ o$, fig. 83. Join $k\ o$; then $k\ o$ is the distance at which the twisting-rules are to be applied on the extrados. In fig. 83, draw $n\ q$ parallel to $m\ p$; then $n\ o\ q$ will be the divergent portion of the winding-strip.

When a bridge skews to the *left*, as shown in fig. 80, plate 8, the winding-strip must be applied on the *right-hand side* of the parallel rule, and *vice versâ*.

The rules here described are to be applied as directed in art. 141.

192. *Templet for the Curve of the Soffit.**—The por-

* The Reader must not be discouraged if he do not, on the first perusal, understand the object of the operations here described. Some assistance may be derived from an inspection of fig. 77, in which figs. 84, 85, 86, and 87 are repeated on a small scale in connection with each other; but the best way would be to lay down the several lines on the surface of a cylinder, when the principle on which the rule is founded becomes immediately apparent.

tion of a coursing spiral included in the length of any voussoir may be treated as an arc of a circle, and may be obtained approximately as follows:—Draw on the platform the lines *a b*, *b c*, fig. 84, plate 8, of any convenient length, making $\angle\ a\ b\ c =$ angle of intrados. On *a b* let fall the perpendicular *c a*. In fig. 85, plate 8, draw $a\ x =$ radius of intrados, and with *x* as a centre draw the arc $a\ c = a\ c$, fig. 84. From *c* let fall on *a x* the perpendicular *c d*. Draw two lines parallel to each other, fig. 86, at a distance apart $= a\ d$, fig. 85. From any point, *b*, in one line as a centre, with radius $=$ *b c*, fig. 84, describe two arcs cutting the other line, as shown at *a* and *c*. This will give three points in the curve, which may then be drawn in with a trammel, as described in art. 64. Make a templet to the curve thus found, and call it templet No. 1.

193. *Templet for marking the Heading-Joints on the Beds.*—Take a sheet of zinc, and mark on it the curve of the soffit with templet No. 1. With intersecting arcs, set up a perpendicular to the curve as *a b*, fig. 87, plate 8, making $a\ b =$ thickness of arch, or a little more. Cut the zinc to the angle *b a c*, as shown by the shaded part of the figure, and this will be the templet required; which call No. 2.

194. *Templet for marking the Heading-Joints on the Soffit.*—This is simply a rectangular piece of zinc of any convenient length, and of which the width is that of a course: it is best however to make it the length of the longest voussoir. Call this templet No. 3; see fig. 89, plate 8.

195. *Arch-Square.*—The arch-square, required for working the soffit from the bed, is precisely similar to that shown in fig. 76, art. 170, and needs no further description.

196. *Method of working the Voussoirs.*—1st *Bed*

Bring one side of the stone to a plane surface. With No. 1, draw on it the curve of the intradosal coursing joint, as *a b c*, fig. 88, plate 8. With No. 2, draw one of the heading-joints, as *a e*. Take the twisting-rules, and, applying the parallel rule to the line just drawn, work the bed *a b c d e* to the proper twist. With No. 2, draw the second heading-joint *c d*. This completes one bed. —*Soffit*. With the arch-square applied so that it shall be always in a plane perpendicular to the axis of the cylinder, work the soffit to a cylindrical surface. If any difficulty is found in applying the arch-square in the proper direction, a small bevel may be applied to the soffit, set to the complement of the angle of intrados, as shown in fig. 89, plate 8. With No. 3 gauge the soffit to its proper width, and mark the heading-joints. This completes the soffit.—*2nd Bed*. This is worked from the soffit with the arch-square, and the heading-joints drawn with No. 2.—*Ends*. These are worked with a straight-edge applied between the joint-lines drawn on the beds with No. 2.

197. *Centering*.—As soon as the abutments have been carried up to the spring, and the impost stones set, the centering must be erected. The ribs should be placed parallel to the face, and not square to the abutments; as the former plan ensures greater accuracy in the curvature of the fronts. The laggings must be securely fastened, and their upper surface planed perfectly true, so as to coincide everywhere with a templet cut to the curve of the soffit. Too much importance cannot be attached to this, as upon it mainly depends the accuracy of the work.

The surface of the laggings having been made perfectly true, the lines of the coursing and heading joints must be marked upon it, to assist the workmen in setting the arch-stones.

This is done in the following manner; which will be understood by reference to fig. 11, plate 2.

Draw the face lines, and, having bisected them, draw a level line along the crown of the centering from centre to centre of each face.

Take the impost rod, and transfer the divisions on it to this centre line. Prepare a thin flexible board as a straight-edge, and, having planed its edges very true, transfer to it with great care the divisions of the heading spiral, which must be set off from the rod previously prepared, as described in art. 188. This straight-edge need not be longer than is necessary to extend from the impost to the crown of the arch. Then, beginning at the extremities of one of the imposts, bend the straight-edge round the centering, and draw a series of heading spirals, from impost to impost, through the divisions on the centre line, and the corresponding lines of the checks on the springing stones. It may be necessary to observe that the laggings must project a little way beyond the fronts of the arch, or there will not be room for drawing the extreme heading spirals. Transfer the divisions on the straight-edge to these heading spirals, taking care that the centre line at the crown passes through the *centre* of a division in each case. Through the points thus found, draw the coursing spirals, which will again coincide with the coursing joints in the soffit of the arch. The heading-joints must then be marked, and the numbers of the arch-stones painted on, so that no delay shall occur in setting the stones, from their being brought in the wrong order.

198. *Face Quoins.—Templets for Soffits.*—The soffits of the ordinary voussoirs are rectangular; but this is not the case with the quoins, the soffits of which are all out of square more or less. The templets for marking off the face-line on the soffits of these stones are best

obtained from the lines on the laggings, which is done by bending round templet No. 3, and cutting off the end to coincide with the face-line.

199. *Templets for Angles of Coursing and Face-Joints.*—In the ordinary voussoirs the heading-joints are all perpendicular to the curve of the soffit. This is not the case with the face-joints, which make varying angles with the coursing joints, according to their distance from the springing; the joints lying between the crown and the acute quoins, making acute angles with the soffit joints, whilst the angles on the opposite halves of the fronts are obtuse angles. There are many ways of obtaining these angles by geometrical constructions; but these methods are very intricate, and require a great many lines. We prefer, therefore, to take these angles at once from the lines on the centering, which may be done with great facility and accuracy as follows:—

Apply templet No. 1 to a thin strip of deal; and, having marked on the latter the curve of the soffit, cut away the superfluous wood, so as to make a corresponding convex rule. Take this rule and frame it to three arch-squares, set in planes perpendicular to the axis of the cylinder, as shown in fig. 90, plate 8; so that when the curved edge, *a b c*, is placed on a coursing joint on the centering, the curved edges of the arch-squares shall coincide with the surface of the laggings. Mark the centre of *a c* as shown at *b*. Then, beginning at the joint nearest to the acute quoin, place the edge *a b c* to coincide with the coursing joint; and so that the face line shall pass through the point *b*. Take a plumb-line with a pointed bob, and pass it carefully along the arris *f* until the point of the bob is exactly over the face line. Mark this point as shown at *e*. Then *a b e* will

be the angle required, and *e b c* will be the angle for the corresponding obtuse quoin. Find the angles for the other joints in the same manner. Take templet No. 2, place it so that its curved side corresponds with *a b*, and cut the templet to the angle *a b e*, and this will be the templet for marking off the face-joint on the adjacent beds of the two first courses from the springing. The remaining templets will be constructed in the same manner.

200. *Angle of Twist.*—As in all books on skew masonry a great deal is said about the angle of twist, it may be desirable that we should say a few words on the subject. The term angle of twist is an expression used to denote the difference between the angle of intrados and extrados, and is often spoken erroneously of as synonymous with the *angle of the twisting rule.** Thus in figure 57 and 58 (art. 142) the angle *c b e* is the angle of the twisting-rule, and *c b d* is the angle of twist, being a somewhat smaller angle, which must necessarily be the case, as may be seen by inspection of fig. 56, as *e f* will always be less than *d g*. In practice however the difference between these angles is not appreciable, and no sensible error will result from considering them as identical.

201. The whole of the projections, bevels, and templets, above described, are shown in a connected form in fig. 77, plate 7; a careful study of which will materially assist the reader in obtaining a clear understanding of the principles which we have endeavoured to explain. There is, however, so much difficulty in understanding the nature of spiral planes without models, that we would recommend the reader to procure a wooden cylinder, say three feet diameter, and to work out upon it all the problems connected with skew masonry. The de-

* That is, when the rules are applied to the length of the stone.

velopments may be made on drawing-paper, and their accuracy tested by bending them round the model. The templets and bevels may be cut out of cardboard; and the accuracy of the face bevels may be proved by etting up in cardboard an elevation of the face, and rying them against it. The construction of a model of his kind is the best method of obtaining a knowledge of the subject, and more will be learnt by this means in few days than could ever be done by the study of lrawings alone.

GROINED VAULTING.

202. *Roman Vaulting.*—The principles of Roman aulting have been explained at considerable length in Section I.; and in Section II., articles 119 to 131, the nethods of obtaining the profiles of the groins, and the evelopments of the soffits of cylindrical vaults, have een fully shown. We have, therefore, in this place nly to apply the application of these principles to ne working of the groins, no other portion of a common roined vault offering any particular difficulty.

203. The simplest way of working a groin-stone is to ring the stone into a cubical form, as shown in fig. 92, late 8; and on the vertical and horizontal surfaces of peration thus obtained, to apply templets taken from full-sized plan and elevation; see fig. 91, plate 8. This the easiest way of proceeding; but the waste of stone very considerable.

204. If the stone to be worked is only sufficiently rge to contain its intended form without any waste, we ust begin by working two plane faces at right angles each other, to contain the heading joints *a b c d*, *b i g h*, g. 92, plate 8. These having been worked, and the rm of the stone marked with a templet taken from a

full-sized section of the vault, the top and bottom bed can be worked with a common square, and the arris lines drawn upon them. The curved soffits can then be finished with a curved rule, cut to the proper curve and applied between the top and bottom arrises. This method makes the most of the stone, and saves the labour of making surfaces of operation; but it requires considerable care to keep the angles perfectly true.

205. The above methods suppose that the main and the cross vault are built in horizontal courses, which would always be done in the Italian style; but it is quite possible to keep the courses of the main vault horizontal, and to make those of the cross vault radiate from the centre of the main vault. This arrangement may be seen in fig. 6 (art. 17). It is only suited to rough rubble-work, as the execution of such a vault in regular masonry would be a most complicated process.

206. *Gothic Vaulting.*—In Gothic vaulting, as explained in Section I., the profiles of the groins are always formed of circular curves, and the forms of the vaulting surfaces are made to depend on the curvature of the groins, instead of the groins following the form of the vaulting surface, as in Roman vaulting.

It is true that, in the decline of the pointed style, elliptical groins were used to a certain extent; but this was after the introduction of vaults of solid masonry, as the fan vault, and the later lierne vaults, which assimilate very closely in their construction, although not in their decoration, to the vaults of the modern Italian school.

For this reason we do not propose here to take into consideration the construction either of fan vaults or of the late pointed vaults, which are chiefly built of jointed masonry.

The construction of a pointed waggon vault of solid

ıasonry is precisely similar in principle to that of a com-ıon cylindrical arch, however complicated the tracery hich may be sunk upon its soffit; and the construction f a fan vault may be accomplished either by the rules ;ven in art. 158 and following articles, or by forming orizontal surfaces of operation, as shown in fig. 10, art. 5; which seems to have been the plan adopted by the ıasons of the middle ages; although in many existing ıults the extrados is parallel to the soffit, the surfaces operation having been chipped off, so as to bring the pper surface of the vault to a curved form.

207. Rib and Pannel vaulting is quite different in its ›nstruction, both from Roman vaulting and from the te pointed vaults of which we have just spoken.

It consists, as has been before explained, of a frame-ork of light ribs, each of which is worked in the same anner as a cylindrical arch; and of light pannels hich rest on this framework, and are either built in ›urses or formed of thin slabs of stone scribed to the bs; the general principle on which the vaulting sur-ces are formed being, that the soffits of the pannels ›ould everywhere coincide with a straight-edge applied a horizontal direction from rib to rib; although when e pannels are built in courses they are made slightly ›ncave as the stones would otherwise have little to keep em from falling. No difficulty occurs in working the ›s themselves, since each stone forms a portion of a lindrical arch; but a considerable amount of projec-›n and transference of lines is required in arranging the rves of the ribs, and to obtain the bevels for working e stumps of the ribs on the boss-stones, at their inter-ctions. We propose, therefore, to conclude this little ›lume by a brief description of the projections required r the execution of a plain ribbed vault, with an expla-

nation of the manner of finding the curvature of the liernes and the bevels for the boss-stones in the simplest class of lierne vaults.

208. The various ribs introduced in Gothic vaulting may be classed under six heads, viz. :—

1st. Transverse ribs, which are placed at right angles to the length of the vault.

2nd. Longitudinal ribs, which are parallel to the length of the vault. If the apartment be vaulted in one span, the longitudinal ribs are called, from their position, *wall ribs*.

3rd. Diagonal ribs, or cross springers. Upon these the main strength of a Gothic vault depends; whilst, in the Roman groined vault, without ribs, the groins are the weakest parts.

4th. Intermediate ribs. These are ribs introduced between the transverse and diagonal ribs, and may be either surface ribs, that is, ribs coinciding with a previously determined vaulting surface; or they may be independent ribs, each of which marks a groin; that is, a change in the direction of the vaulting surface.

5th. Ridge ribs. Ridge ribs, as essential portions of the construction of a vault, are unnecessary where no intermediate ribs are introduced; and, in this case, the ridge ribs of the Gothic vaults were frequently built in with the pannels instead of being previously built as a portion of the framework of the vault. An example of this may be seen in a vault in the ruins of Wingfield Manor House, Derbyshire. In this vault, the central bosses have been prepared for the reception of the ridge ribs; but the latter, instead of being moulded to correspond with the mouldings of the bosses, are plain canted strips, built in as keystones to the rubble arches forming the pannels. Where intermediate ribs are introduced,

he ridge ribs become essential as struts to keep the ormer in their place previous to the insertion of the ›annels.

In making the ridge ribs form part of the framework ·f the vault to be built with a light skeleton centre, a .ifficulty occurs, unless the vault be highly domical in :s structure; as there is otherwise nothing but the entering to keep them in their places until they an be supported by the pannels. A common remedy or this was to make each portion of the ridge from ·oss to boss slightly concave. A very striking example ·f this may be seen at Lincoln Cathedral; where the osses appear to be placed in a level line, or nearly so, ·hilst the ridge ribs of the several compartments form a eries of flat arches between them.

6th. Liernes. These are short ribs introduced be-ween the principal ribs, so as to form ornamental atterns. Their forms are generally governed by the aulting surface, although they are built as separate rches, not as portions of the pannel. When many ernes are introduced, the construction of the vault ecomes complicated; and, instead of the skeleton entre, which is all that is requisite for constructing a lain ribbed vault, a regular boarded centering must be rovided. In the complex lierne vaults, the principle of ıe plain ribbed vault, viz. the making the vaulting urface to depend upon the curvature of the ribs, is, in a reat measure, lost sight of; as it becomes necessary rst to design the general form of the vault, with which ıe curves of the ribs must be made to correspond.

209. *Curvature of the Ribs.*—In designing a plain .bbed vault, it is simplest to begin with the transverse ıbs, as their form, in a great measure, governs the ppearance of the work.

Each rib may be struck as a single arc of a circle, or from two centres; so that each pair of ribs forms a four-centered arch. Whichever plan is adopted, the centre of the curve at the springing should be *on* the springing line; neither above nor below it, as either of these positions produces an unpleasant effect; the curve in the former case becoming horse-shoed, and, in the latter, forming an acute angle with the springing line.

Fig. 93, plate 8, shows the plan of a quarter of one compartment of a ribbed vault, with the elevation of each rib placed on its plan—*a* 1 *b* is the plan, and *a a* [1] B, the elevation, of the transverse rib.

210. The transverse ribs having been decided on, the next thing to be settled is the form of the cross-springers, and here some little arrangement is necessary. Two objects should be kept in view; the first, to make the radius of curvature as nearly as possible the same as that of the transverse ribs; and the second, to make the curve at the springing start at right angles to the springing line. The simplest way of accomplishing these objects is to strike the transverse and the diagonal ribs with the same radius; the centre of the curve being placed in both cases on the springing line. This is shown in fig. 94, plate 8, where *a* B is the elevation of the transverse, and *a* C that of the diagonal, rib. This was a common arrangement in Continental vaulting; but it has the peculiarity of producing a highly-domed vault, the intersections of the cross-springers at C being much above that of the transverse ribs at B. If we wish to keep the ridges horizontal, we have a new condition introduced, and the complete solution of the problem cannot be effected with single arc ribs only. If we confine ourselves to ribs formed of a single arc, we may make the diagonal rib of the same radius as the trans-

rse; placing the centre below the springing line, as fig. 95, plate 8; or we may keep the centre of the agonal rib on the springing level, and diminish the dius, as shown in fig. 96, plate 8.

By the employment of two-centred ribs, however, the justment of the curvature can be accomplished with eat facility; this is shown in fig. 97, plate 8, where e first portions of the diagonal and transverse ribs are uck with a common radius *a d;* the remainder of the nsverse rib being struck from *f*, and that of the diagonal from *e*, so that each pair of diagonal ribs forms a ree-centred arch, of which the flatness at the crown concealed by the boss. These examples will suffice to ow the variety of ways in which the curvature of the gonal ribs may be determined.

211. The curvature of the cross-springers determines general plan of the spandril, and this governs, to a tain extent, the curvature of the intermediate ribs. e longitudinal rib may be determined either as shown igures 96 and 97, or the proportion of the rise to the n may be kept the same as in the transverse ribs and springings stilted, as shown in the elevation of the l rib $e\ e^1$ F, fig. 93. This last arrangement was a y common one in church roofs; the stilting of the l ribs being necessary in order to leave proper space the clerestory windows.

'o ascertain the general plan of the spandril solid, any point, as a^1, halfway up the transverse rib, and fall the perpendicular a^1 1. Set off this height on elevations of the diagonal and wall ribs, and from points c^1, e^1, where a horizontal line at this level cuts ribs, let fall the perpendiculars c^1 2 and e^1 3. Join , 2,3; then a, 1 2 3 e, is the general plan of the idril at the height a^1.

We have already spoken (Section I., art. 19) of the variety of form that may be produced in the middle plan of the spandril by a slight alteration in the curvature of the ribs; and the reader will, therefore, understand, without further explanation, the method about to be described of obtaining the curves of the intermediate ribs from this middle plan. Thus let it be determined to make the intermediate ribs project before the lines 1,2; 2,3. Design the plan *a* 1 4 2 5 3 *e*, so as to give to the spandril the form that may be wished; and from the points 4, 5, erect the perpendiculars 4 g^1, 5 1^1, each respectively equal to 1 a^1. Then the form of the ridge having been previously decided on, (in the example shown in fig. 93, both the longitudinal and transverse ridges are made horizontal,) we have three points in each intermediate rib through which to draw the required curve, which may be struck either from one or two centres, according to circumstances. In fig. 93, the whole of the ribs are made single arcs of circles; the centre of the intermediate rib *i k* being placed above, and that of the rib *g h* being placed below, the springing level. If the ridge-ribs are not horizontal, their elevations must be drawn before those of the intermediate ribs, and the points H, K, ascertained accordingly.

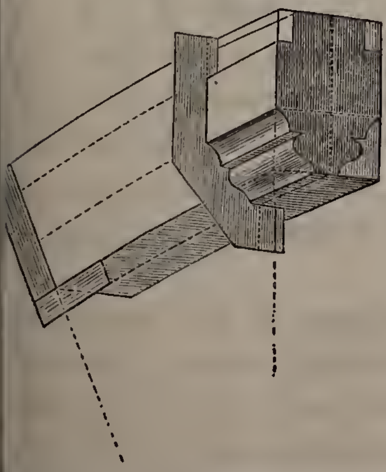
212. For the purpose of showing the manner of finding the curvature of a lierne lying in a given vaulting surface, we have introduced in fig. 93 two liernes I *h* and I *k*. From any convenient point *m* on the diagonal rib about halfway between I and *d*, set up the perpendicular *m* M, and from I set up the perpendicular I L. Draw M^1 *m*, L I^1, parallel to the springing. On the elevation of the intermediate rib *g* H set off H n^1 = D m^1 draw n^1 N parallel to the springing, and from N let fall the perpendicular N *n*. Join *n*, *m*, cutting I *h* at *p*; *n*

ill be the plan of a level line on the soffit. On I h ·ect the perpendiculars h H^1 and p P, making h H^1 = l^1 and p P $= m^1\ l^1$. Then I, P and H^1 are three points ι the soffit of the lierne, through which the required ırve may be readily drawn with a trammel.

The curvature of the lierne I k is obtained in the .me manner.

213. The voussoirs forming the ribs are worked in a ·ry simple manner, as each stone forms a portion of a ʼlindrical arch. Two parallel faces of operation are ·st formed, at a distance apart equal to the maximum ickness of the rib, and on one of these faces the curve the soffit is marked with a templet. The soffit is en worked with a common square, and the ends of e stone cut to radiate from the curve of the soffit, .her with an arch-square or with a templet applied on ıe of the faces. The profile of the mouldings is then ɪrked on the ends with a templet, and the soffit gauged to its proper width; lastly, the lines bounding the parallel faces of the rib are scribed on the latter with a gauge applied to the soffit, and the mouldings are sunk by means of a mould applied to these lines and to the arris lines of the soffit as shown in fig. 98, which however is only intended to show the .nciple of operation, as practically each member is ·rked in succession, with a separate templet, surfaces operation being formed, containing the arrises of the ɔuldings between which the templets are applied.

Fig. 98.



A rebate must be sunk in the upper part of each face, to receive the pannels.

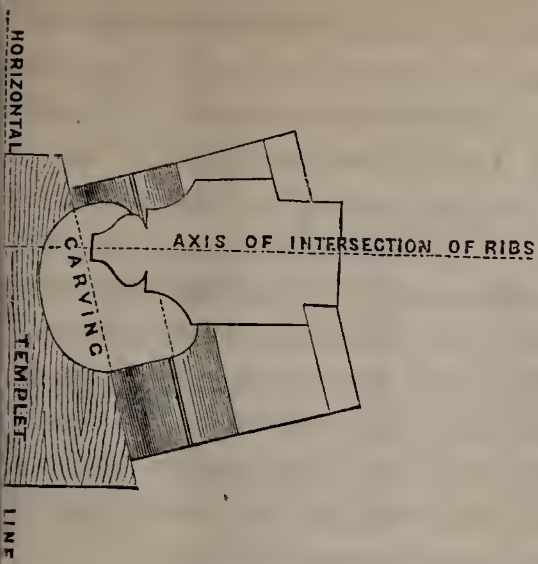
214. In arranging the positions of the feet of the ribs upon the impost, care must be taken to make each rib as much as possible distinct and independent; which is done by making the ribs start at different distances from the intersections of their centre lines. This will be understood by reference to fig. 93; in which the intermediate ribs are made to spring from behind the intersections of the diagonal and transverse and longitudinal ribs. The ribs cease to be worked as separate arches, from the level at which the mouldings begin to intersect each other. Below this point, the springing must be worked in horizontal courses; the upper bed of the top course being cut into a series of inclined planes, so as to form a proper abutment for the foot of each rib.

To work these springers the top and bottom beds are first worked, and the centre lines of the ribs marked upon them. The position of the soffit of each rib is then transferred to these lines from a full-sized elevation, and the soffits worked with convex templets applied to the top and bottom arrises. Lastly, the soffits are gauged to the proper widths, and the mouldings worked out with moulds applied in a direction radiating from the curve of each rib.

215. In working the keystones at the intersections of the ribs some little difficulty occurs, inasmuch as from each rib being a separate arch, its middle section must be a vertical plane, and the mouldings of the ribs will therefore not mitre, but intersect each other in a very awkward manner: see fig. 99.

To hide this, the keystones are worked with a round lump or *boss*, ornamented with foliage and sculpture; so

Fig. 99.



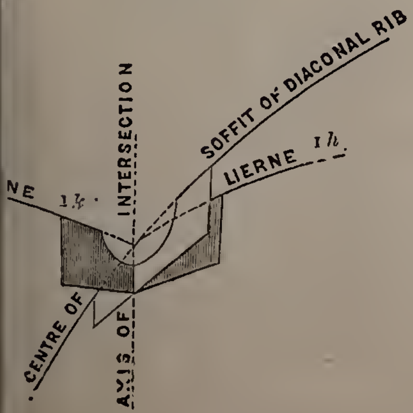
that the mouldings die into the ornament without intersecting each other.

216. The method adopted by the Gothic masons to obtain the form of the boss-stones, and the position of the stumps of the ribs, was to take rge block, and to work upon it an upper horizontal face of operation, to which the centre lines of the ; were transferred from a full-sized plan of the vault; the form of the soffit was then obtained by squaring n from this upper surface.

17. This method occasions much extra labour, and eat waste of stone. The following is preferable:— pose it is required to work the boss-stone at I, fig. 93, e 8.

Iake a short templet to the curve of the soffit of the rib *c d*, so that its bottom edge shall be horizontal; and mark on it a vertical line, corresponding to the axis of intersection of the ribs (see fig. 100). Make similar templets for the two liernes, I *h*, I *k*. Mark on each

Fig. 100.



templet the form of the boss, and cut away the upper edges; so that when the three templets are applied to the soffit of the finished stone, the ends of each shall exactly coincide with the soffit of each rib; the carving of the boss lying in the hollows thus formed. To work the stone, begin by sinking a draft to the templet for the diagonal rib; and then, placing one of the lierne templets at the proper angle with the first templet, sink it into the stone until the *horizontal* edges of the two are out of winding. Apply the third templet in a similar manner. Knock off the superfluous stone square to the drafts, and we have then three curved surfaces of operation containing the soffits of the three ribs. The rest of the operation presents no difficulty.

The above method applies to all the boss-stones in a vault, whatever their shape or position, and will be understood by inspection of figs. 99 and 100.

218. The stumps on the boss-stones should always be squared to form proper abutments for the ends of the ribs. This was not always done by the mediæval architects, who often worked the stumps of the liernes on the bosses, so as to form acute angles with their soffits.

APPENDIX.

E following interesting Investigation has been kindly forded by T. A. Walter, Esq., the Government Architect at shington, United States, which will, it is presumed, be t instructive, on this valuable building material :—

ort of Professor Walter R. Johnson on the Building Stone sed in constructing the foundations of the extension of the 'nited States Capitol.

1 conformity with directions and instructions to test the e used in the foundation walls of the extension of the itol, with respect to their strength and durability, I proed to inspect the walls of the two wings, and to note, as as practicable, the general character, and the apparent rences in the stones which have actually been laid in the s.

here was no difficulty in ascertaining that some diversity, in appearance and texture, existed among the materials, it consequently became evident that no one sample which l be selected would adequately represent the entire mass. therefore became necessary to select a moderate number imples, from different parts of the two wings, and, as far icable, with reference to the proportions in which they ed to prevail in the walls.

is evident that this proportionality could only be approxily obtained.

is confidently believed that the extremes of character been reached, but it is to be remarked that the sample h was taken to show the least probable strength was one very few which appear mostly in the foundation of the 1 wing.

Three samples were taken from the walls of each wing, besides which a block lying within the north wall was taken to furnish a series of cubes of different sizes to test the question of increase of resistance according to enlargement of area, and one sample of the sandstone used in two or three of the interior projections only of the walls of the south wing. This sandstone is of the same character as that of which the Capitol is built.

The samples were prepared for trial by sawing out from each six cubes of one and a half inch on a side, which were all carefully dressed by rubbing down in the ordinary manner; and the faces which were to receive the compressing force were made parallel, and all the specimens of very nearly the same height, by finishing within a steel frame, which enclosed and held all the six specimens at the same time, and which, being turned over after dressing one set of faces, allowed the opposite set to be rubbed in like manner, and made parallel to the first.

This frame is understood to be the same which was employed by Messrs. Totten, Henry, Ewbank, and Walter in their recent trials of the marbles. Of the six cubes from each sample, one was selected and reserved for trials of atmospheric effects, and the others carefully gauged to the thousandth part of an inch, preparatory to the operation of crushing. In general the specific gravity of every specimen was taken in the ordinary way before crushing.

For the sandstone it was found necessary to take account of the water absorbed when immersed for the purpose of taking its specific gravity.

The machine used for crushing is that employed for the ordnance service of the Navy, in testing the various materials required for that service.

It consists essentially of a lever of the first kind, having fulcrum distances of 20 to 1, acting by its shorter arm on a lever of the second order, having fulcrum distances of 10 to 1, and consequently the relation of the weight applied to the first lever to the force exerted by the second is one to 200.

The fulcra of the machine are all steel knife-edges, and no allowance is made for friction.

The compression of the specimens, when under trial, was ascertained from time to time by suitable callipers applied by steel plates above and below the stone, and the modulus of resistance to compression was thus ascertained with considerable exactness. This modulus varies considerably in differen

mples, and even in different cubes from the same sample. order to obtain a standard of comparison of the different ecimens of the stone operated on, a sample of a rock was sted largely used in this country, and to some extent by overnment, for building and other purposes.

This was the Quincy sienite, which, as will be observed by 'erence to the Table, sustained a very high pressure before ushing. In testing the action of the atmosphere on the fferent samples, I may remark that, for the particular purse of the foundations of the Capitol, it was considered that e trials of the effect of frost are very important, as it is unrstood that these foundations will, when the building is comted, be embanked in such a manner that frost will never ch them.

For other uses to which this stone may be applied these als may be of much importance. To some extent an exption from water percolating the soil will also apply to the ndations, since the water falling upon the building will be stly carried away by pipes and drains, and the shielding of surface by pavements or flaggings will tend to keep dry foundation walls.

Chemical trials were selected of such of the samples as apred to represent the exactness of strength to resist crush-, and to subject them to such reagents as are likely to most efficient in nature in causing disintegration or dissoon.

The two samples taken for chemical analysis were those nbered *one* and *seven* of the accompanying Table; and for a chanical separation of certain mineral constituents No. 5, the same Table, was chosen, being one of those which apred to have been freed from the action of atmospheric innces prior to its removal from the quarries.

For some of the other samples, likewise, the effect of heatwas noted by way of comparison. The quarries from which stone is stated to have been derived for the south wing is wn as the Smith quarry, and those from which that of the th wing is taken are the O'Neill quarries. One of the Neill quarries is immediately adjoining that of Smith, and se two appear to furnish stone of essentially the same chaer.

The other quarries of O'Neill are a few hundred feet lower n the canal. At all these quarries it is judged that stone be found, representing every variety embraced in the es of specimens selected for trial from the foundations of

the Capitol. At all of them there is a covering of greater or less depth, from *one* or *two* to *ten* or *twelve* feet of soil, sand, gravel, and clayey matter, with some rolled pebbles, all of which repose in beds, more or less regular, upon the upper edges of the micaceous rock, worked in the quarries. This rock lies inclined southwestwardly, in an angle of about 50 degrees; and the natural beds and fissures of the stone afford passage to the surface water to penetrate to a considerable distance below the upper edges. This penetration has caused, in some parts, a discoloration, accompanied by a greater or less alteration of the consistency of the rock, the natural bluish or greenish colour being changed to a yellowish-brown or drab colour; and for about twenty or twenty-five feet from the top, the rock has been so affected by these surface influences as to be unfit for use in building.

Below that level, varying however in the different strata, the workable stone is found. In some of the softer portions it appears that the decomposition has extended further down than in adjoining firmer beds.

In breaking the blocks the depth to which atmospheric influences have penetrated is in general sufficiently indicated by the colour. A careful inspection enables the quarryman to reject those parts which have been materially affected by the influences above referred to; and the large heaps of rejected matter near the quarries, evince the necessity and the exercise of a discrimination in the selection of such parts as are fit for building purposes. The discoloration of the stone is sometimes only superficial, or extends to the depth of but a few lines. The upper edges of the rock next to the covering of sand, gravel, etc., afford little more than a mass of micaceous sand, with barely cohesion enough to bear handling.

The rock in its normal, or solid state, appears to occupy an intermediate place between *true* mica slate, of which flag-stones are made, and gneiss, which has the mineral composition of granite. This rock has quartz and mica in large proportions as compared with feldspar. It exhibits many nodules of quartz, nearly pure, and small garnets, together with iron pyrites, and magnetic oxide of iron.

A Table is given exhibiting, first, the number of samples tested; second, the part of the foundation walls from which they were severally taken; third, the numbers of the several specimens taken from each sample; fourth, the external characters of each specimen; fifth, the specific gravity; sixth, the weight of each sample per cubic foot, derived from the average

ecific gravity; seventh, the height of each specimen crushed; ghth, the observed compression; ninth, the force producing e observed compression; tenth, the area of the base of each ecimen operated on; eleventh, the modules of resistance to mpression of each specimen; twelfth, the average modulus r each sample; thirteenth, the average crushing force per uare inch, in pounds; fourteenth, the absorption of water each sample; and, fifteenth, the loss of each sample by the ect of heat.

1	2	3	4	
No. of the Sample.	Parts of the Foundation Walls from which the Samples were taken.	Mark of the Specimen.	External Characters of each Specimen.	Specific Gravity of the
1	From the inner wall, south-east corner of the north wing, and about halfway up the wall, from a block partly uncovered, owing to the wall being unfinished.	1	Nodule of flint on one side; a few minute crystals of pyrites.	2·7
		2	Nodule of flint near one corner . . .	2·7
		3	Colour nearly uniform grey; no pyrites observed.	2·7
		4	Whitish band, with pyrites on one side; light spot on opposite side.	2·8
		5	White spot on one corner; the rest dark grey; pyrites on two sides.	2·7
2	From an unfinished buttress on the inside of the wall, near the north-west corner of the south wing, and about halfway up from the bottom.	1	Colour dark grey; few specks of pyrites; nodule of quartz on one side.	2·7
		2	Colour dark grey; few specks of pyrites; thin seams of micaceous matter.	2·7
		3	Numerous dark red specks of garnets; quartz nodule; few specks of pyrites; colour dark grey.	2·7
		4	Colour dark grey; two thin beds of greyish white; dark brown specks of garnets, and one or two minute crystals of pyrites.	2·8
		5	Colour dark grey; garnets and pyrites very sparse.	2·7
3	From the inside of the wall, near the north-east corner of the north wing, about the middle height of the wall, still unfinished.	1	Colour dark grey; five or six specks of pyrites; brown siliceous matter, in fine particles.	2·7
		2	Five specks of pyrites visible; several garnets in light coloured spaces; small cavity on one side.	2·8
		3	Colour dark grey; two specks of pyrites visible; garnets in light spaces.	2·
		4	A nodule of flint; three or four fine specks of pyrites; garnets in light coloured spaces.	[illegible]
		5	Two or three light grey spaces; four specks of pyrites.	2·

7	8	9	10	11	12	13	14	15
Height of the Specimens in Inches.	Observed Compression in 1-10,000 of an Inch.	Force producing the observed Compression in pounds Avoirdupois.	Area of Base of Specimens in Square Inches.	Module of Resistance to Compression in Pounds for a 1-Inch Base.	Average Modules of Resistance to Compression for each Sample.	Crushing Force per Square Inch in Pounds Avoirdupois.	Absorption of Water by a Cube of 1½ Inch in Grains Troy.	Loss by a 1½-Inch Cube in Freezing 30 times in 1-100 of a Grain.
1·415	100	35·000	2·3639	2,048,900				
1·402	35	10·000	2·3531	1,702,100				
1·410	25	10·000	2·4312	2,319,800	2,205,800	20·715	1·20	6
1·408	60	20·000	2·3686	1,981,300				
1·408	40	20·000	2·3648	2,977,000				
1·410	50	35·000	2·3104	4,272,000				
1·402	90	35·000	2·2906	2,380,400				
:·419	35	35·000	2·2738	6,240,700	4,318,800	18·702	0·81	8
·412	55	35·000	2·3341	3,849,400				
·416	50	40·000	2·3057	4,901,800				
·404	70	40·000	2·3470	3,417,200				
·405	25	30·000	2·3057	7,312,300				
·407	40	35·000	2·3701	5,194,300	5,570,500	16·866	0·65	27
408	25	35·000	2·3406	8,421,800				
415	35	20·000	2·3055	3,506,800				

1	2	3	4	5
No. of the Sample.	Parts of the Foundation Walls from which the Samples were taken.	Mark of the Specimen.	External Characters of each Specimen.	Specific Gravity of the Specimens.
4	From the bottom of the wall (at the opening left for carts), in the north-west corner of the north wing. The block from which this sample was detached rests directly on the earth.	1	Colour dark grey; a few blocks of whitish matter.	2·721
		2	Three small nodules of quartz on different sides, thin irregular bands of whitish matter resembling talc, but probably is mica.	2·767
		3	One white band containing pyrites; white matter very easily cut; dark-coloured siliceous matter in spots.	2·78
		4	Flint at one corner, white quartz at another; one or two specks of pyrites.	2·75
		5	Small nodule of whitish matter resembling "feldspar."	2·79
5	From the loose stones lying near the north wall, inside the north wing.	1	A block one inch on a side; dark bluish-grey.	2·7
		2	Block two inches on a side	2·7
6	From a part near the top of the wall still unfinished, on the south side of the south wing.	1	Quartz nodule, colour light grey; pyrites; long nodule of flint on one side; whitish specks of partly decomposed feldspar penetrated by atmosphere.	2·7
		2	Two crystals of pyrites; whitish bed mica, greenish in certain parts; decomposing feldspar; no brown streak.	2·8
		3	Light grey specks; no pyrites; brownish streak crosses the beds; a few garnets.	2·7
		4	Brownish streak vertical to beds; no pyrites observed; numerous specks of yellowish-white feldspar.	2·7
		5	No nodule of pyrites, 1–5th of an inch in diameter; light grey spot; rhombic white spaces.	2·7

7	8	9	10	11	12	13	14	15
Height of the Specimens in Inches.	Observed Compression in 1-10,000 of an Inch.	Force producing the observed Compression in pounds Avoirdupois.	Area of Base of Specimens in Square Inches.	Module of Resistance to Compression in Pounds for a 1-Inch Base.	Average Modules of Resistance to Compression for each Sample.	Crushing Force per Square Inch in Pounds Avoirdupois.	Absorption of Water by a Cube of 1½ Inch in Grains Troy.	Loss by a 1½-Inch Cube in freezing 30 times in 1-100 of a Grain.
1·416	65	30·000	2·3639	2,764,500				
1·420	35	30·000	2·2852	5,326,000				
1·415	60	31·000	2·3424	3,120,700	3,263,400	15·978	0·90	11
·415	45	20·000	2·3441	2,674,200				
·410	100	40·000	2·3195	2,431,600				
·032	. .	. .	1·0660					
·00	. .	. .	3·0791	. . .	. . .	15·865	0·40	9
·405	80	20·000	2·2862	1,536,200				
·405	70	15·000	2·2320	1,348,600				
405	70	20·000	2·2846	1,757,000	1,486,600	12·944	4·20	19
400	100	25·000	2·3119	1,513,900				
404	140	30·000	2·3604	1,277,300				

1	2	3	4	
No. of the Sample.	Part of the Foundation Walls from which the Samples were taken.	Mark of the Specimen.	External Characters of each Specimen.	Specific Gravity of the
7	From a block in the second tier from the ground, inside of the wall, near the south-east corner of south wing. The part from which it was taken is a projection beyond the face of the wall.	1	Colour lighter than any of the preceding; no pyrites observed.	2·7
		2	Colour as the preceding; garnets on one side; no pyrites.	.
		3	Colour as above; two nodules of quartz; one speck of pyrites; garnets.	2·7
		4	Grey, with short strips of greenish matter; one nodule of quartz; no pyrites.	.
		5	Nodule of quartz; no pyrites; light grey mottled colour.	2·7
8	From a block of sandstone lying near one of the three interior projections on the south side of the south wing, which are constructed of the same material.	1	Reddish-yellow colour; quantities of quartz cemented by feldspar; small cavity.	.
		2	ditto ditto ditto . .	.
		3	ditto ditto ditto . .	1·9
		4	ditto ditto ditto . .	.
	The Aquia Creek sandstone.	5	ditto ditto ditto . .	.
9	A sample of sienite from the "Wigwam Quarry," Quincy, Mass., tried for comparison, being a material much employed in public buildings, etc. etc.	1	Colour grey or mottled; hornblende, quartz, and feldspar visible and variously intermixed.	2·6
		2	. . . .	2·6
		3	. . . .	2·6

7	8	9	10	11	12	13	14	15
Height of the Specimens in Inches.	Observed Compression in 1-10,000 of an Inch.	Force producing the observed Compression in pounds Avoirdupois.	Area of Base of Specimens in Square Inches.	Module of Resistance to Compression in Pounds for a 1-Inch Base.	Average Modules of Resistance to Compression for each Sample.	Crushing Force per Square Inch in Pounds Avoirdupois.	Absorption of Water by a Cube of 1½ Inch in Grains Troy.	Loss by a 1½-Inch Cube in freezing 30 times in 1-100 of a Grain.
1·405	. .	. .	2·3400					
1·408	80	10·000	2·3149	760,300				
1·400	50	10·000	2·2970	1,020,600	1,400,600	8·156	5·88	12
1·404	40	5·000	2·1975	798,600				
1·410	30	15·000	2·3320	3,023,200				
1·413	30	10·000	2·3087	2,040,100				
·406	. .	. .	2·3028					
·417	45	10·000	2·2950	1,374,900	1,584,400	5·245	199·00	72
·410	45	10·000	2·2719	1,379,000				
·414	40	10·000	2·2897	1,543,900				
·410	115	60·000	2·2801	3,266,200				
·410	80	65·000	2·3073	4,954,100	4,990,150	29·330	5·25	7
·255	. .	. .	1·6320					

In conducting the experiments on crushing, the opportunity was embraced of ascertaining the amount of compression which the stone received under certain loads to which it was subjected. The observations have a practical bearing when applied to materials of variable character entering into the same structure.

If the weakest varieties were at the same time those which could bear the least compression, it might happen that the blocks of stone having little strength to resist crushing, as well as little capacity to undergo compression, might be crushed and destroyed, while the stronger kinds would be yielding to the compressing force and would be eventually brought to bear the whole load. If, on the contrary, the weaker varieties were capable of yielding to compression, without finally giving way until considerably condensed by pressure, they would still preserve their integrity, though so much compressed as to allow the stronger stones in close proximity to them to bear more of the superincumbent weight than belonged to the area of their bearing surfaces. As the compressibility of stones may be considered to arise, in part at least, from their porosity, and as the latter property measures, to some extent, the power of the stones to absorb fluids, it ought to follow, that when a stone has become porous by a partial decomposition, it should be both more compressible by a given force, and more absorbent of fluids than it was in its natural or unaltered condition. The experiments furnish a remarkable confirmation of this view. The table proves that the samples which had been altered by partial decomposition (Nos. 6 and 7) were much more compressible; that is, they gave a lower *modulus of resistance by compression* than any of the samples which were in the ordinary unchanged state of the blue rock. The same altered samples were likewise more absorbent of water than those which were unaltered. The following short table shows the modulus of resistance and absorption of water, arranged with reference to increasing resistance to compression, and to the admission of water.

Number of sample.	Modulus of resistance to compression.	Absorption of water in grains.
7 weathered stone .	1,400,600	5·88
6 " .	1,480,600	4·20
1 not weathered .	2,205,800	1·20
4 " .	3,263,400	0·90
2 " .	4,318,800	0·81
3 " .	5,570,500	0·65

Che differences of compressibility are obviously not solely : to atmospheric action.

t will be remarked that, instead of the usual term "modus of elasticity," the expression "modulus of resistance to ıpression" is used, which seems to be more appropriate to ress that character or property of building materials, which ractically applied in architecture.

minations to illustrate the Effects of Atmospheric Influences on the Stone.

ı testing the action of frost, the process was applied of zing the specimens after moistening them with distilled ːr.

his mode of experimenting (not now allowed for the first) has the advantage over other processes sometimes re-ːd to for imitating the effect of freezing, in producing both chemical and the mechanical actions on the stone which rally result from atmospheric humidity and a freezing ɔerature.

ıch cube subjected to freezing was enclosed in a thin llic box, furnished with a suitable covering, and the whole s of boxes containing the specimens was placed within a r vessel of thin metal, which was surrounded by a freez-nixture. Care was of course taken that all the particles ːhed from each cube by the freezing should remain in its box. The gain in the weight of the box, after thirty re-ons of the freezing process, as ascertained by a balance ɔle to the two-hundredth part of a grain, gave the loss ı the stone had suffered under this treatment. Both in ct to the absorption of water and to the influence of frost, l be observed that the strong rocks, such as sample No. 1 ː blue quartzose mica slate, and the Quincy sienite (sam-o. 9), manifest great power to resist the disintegrating ı of these powerful causes. While sample No. 1 lost only ɔf a grain by frost, No. 6 lost $\frac{9}{100}$, No. 7 $\frac{11}{100}$, and the ı Creek sandstone, No. 8, lost $\frac{72}{100}$, or exactly 12 times as as No. 1. While the sample No. 5, a very sound and ıct variety of the blue rock, absorbed but $\frac{4}{10}$ of a grain of . No. 6 took 4·20, No. 7 5·88, and the Aquia Creek one 199 grains.

ː latter acted in fact like a sponge, and became com-y wet throughout.

s was proved by crushing some cubes of that stone im-

mediately after they had been immersed in water. It is proper to state that the absorption of water is represented by the difference in weight, ascertained by first weighing the specimens after being thoroughly dried, and again after being permitted to absorb water by the aid of the exhaustion of an air pump, and the subsequent pressure of the atmosphere while immersed in a vessel of water within the receiver.

THE END.

BRADBURY AND EVANS, PRINTERS, WHITEFRIARS.

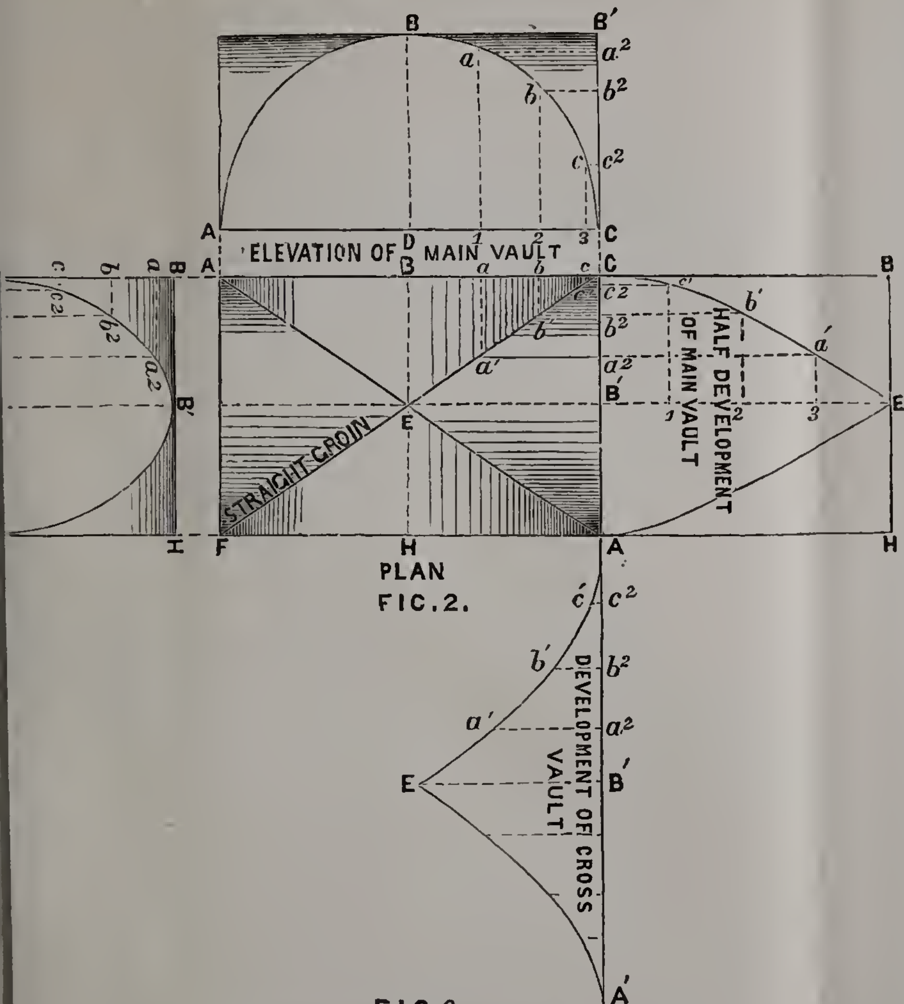


FIG. 2.

FIG. 3.

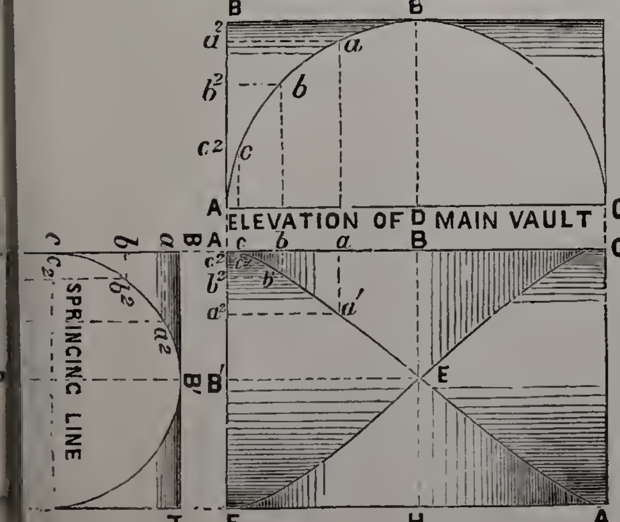


FIG. 18

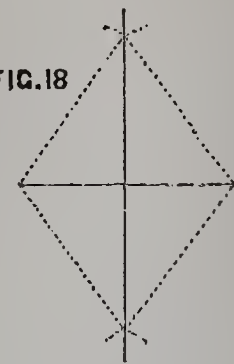
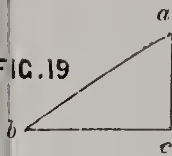


FIG. 19



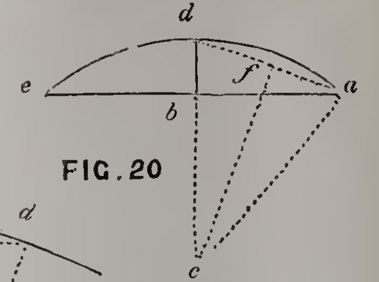


FIG. 20

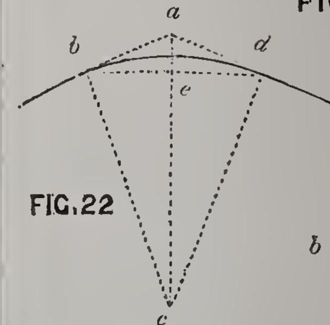


FIG. 22

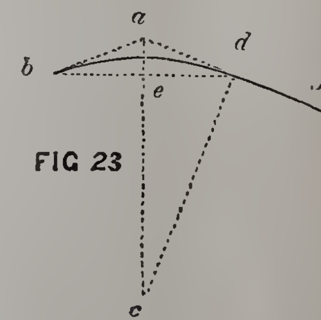


FIG. 23

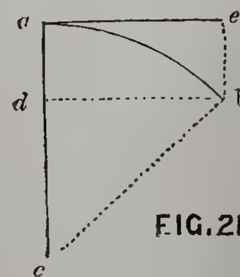


FIG. 21

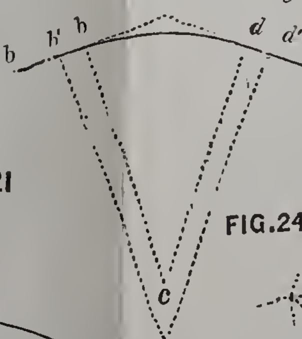


FIG. 24

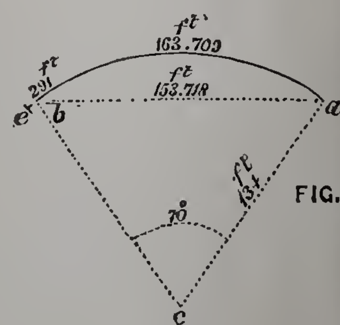


FIG. 25

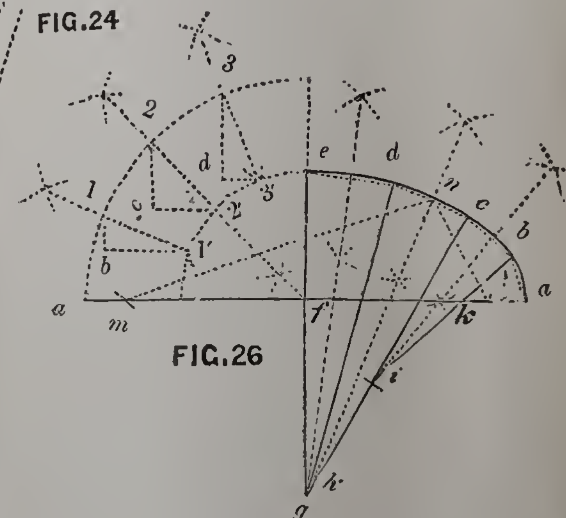


FIG. 26

FIG. 27

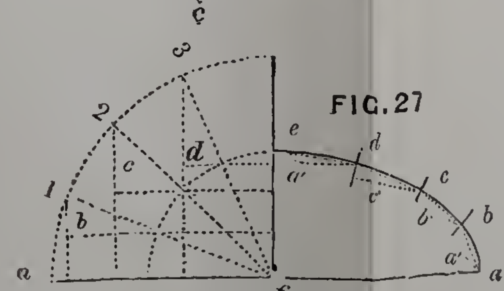
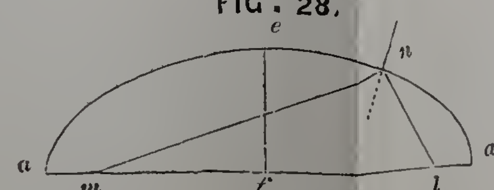


FIG. 28.



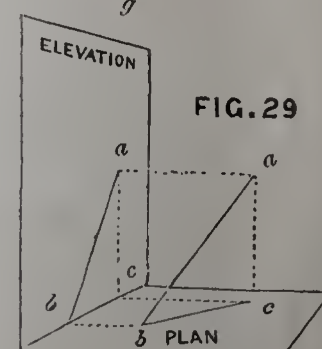


FIG. 29

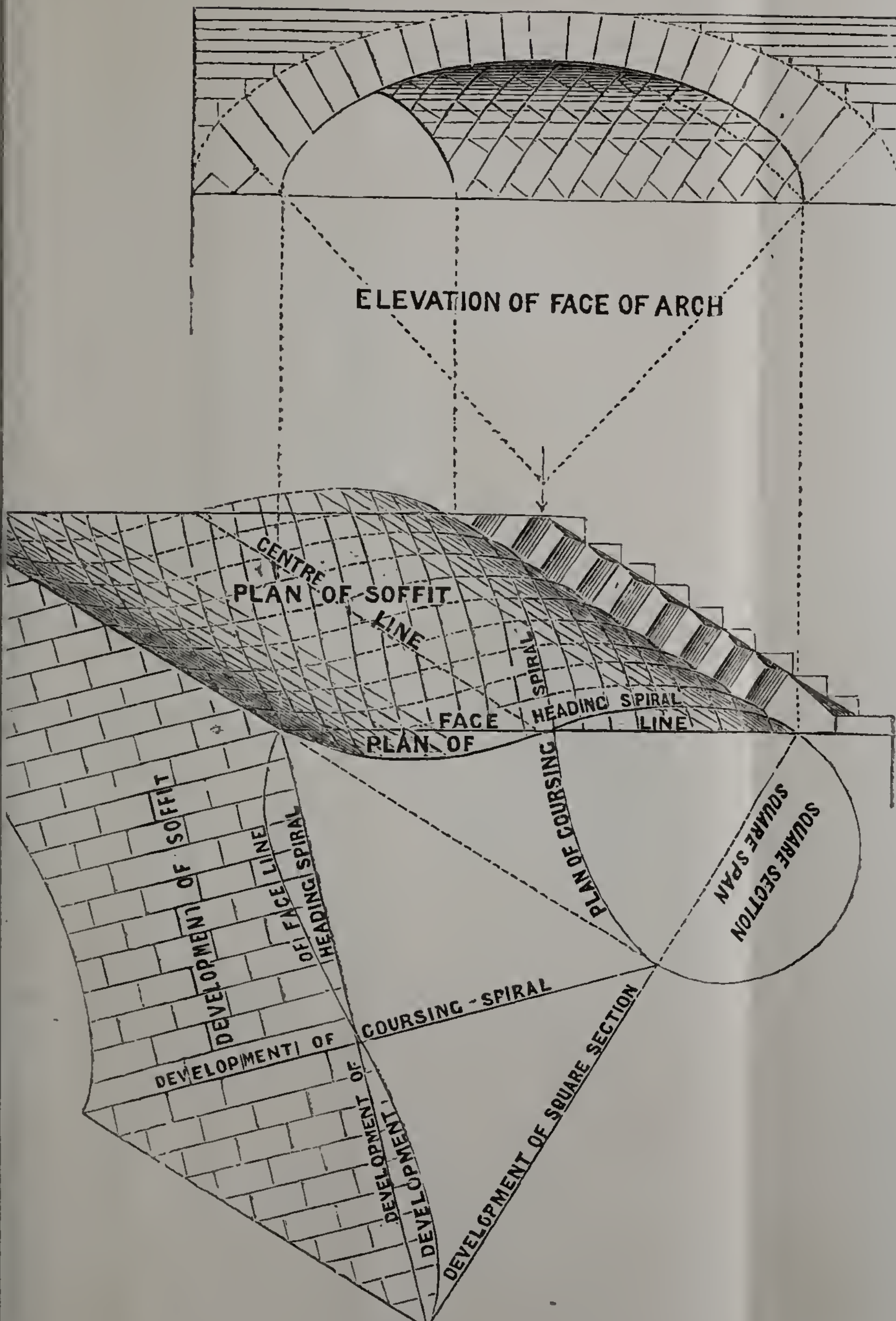

ELEVATION OF FACE OF ARCH
CENTRE
PLAN OF SOFFIT
LINE
SPIRAL
HEADING SPIRAL
LINE
FACE
PLAN OF
PLAN OF COURSING
SQUARE SPAN
SQUARE SECTION
DEVELOPMENT OF SOFFIT
OF FACE LINE
HEADING SPIRAL
DEVELOPMENT OF
COURSING - SPIRAL
DEVELOPMENT OF
DEVELOPMENT
DEVELOPMENT
DEVELOPMENT OF SQUARE SECTION

FIG. 11.

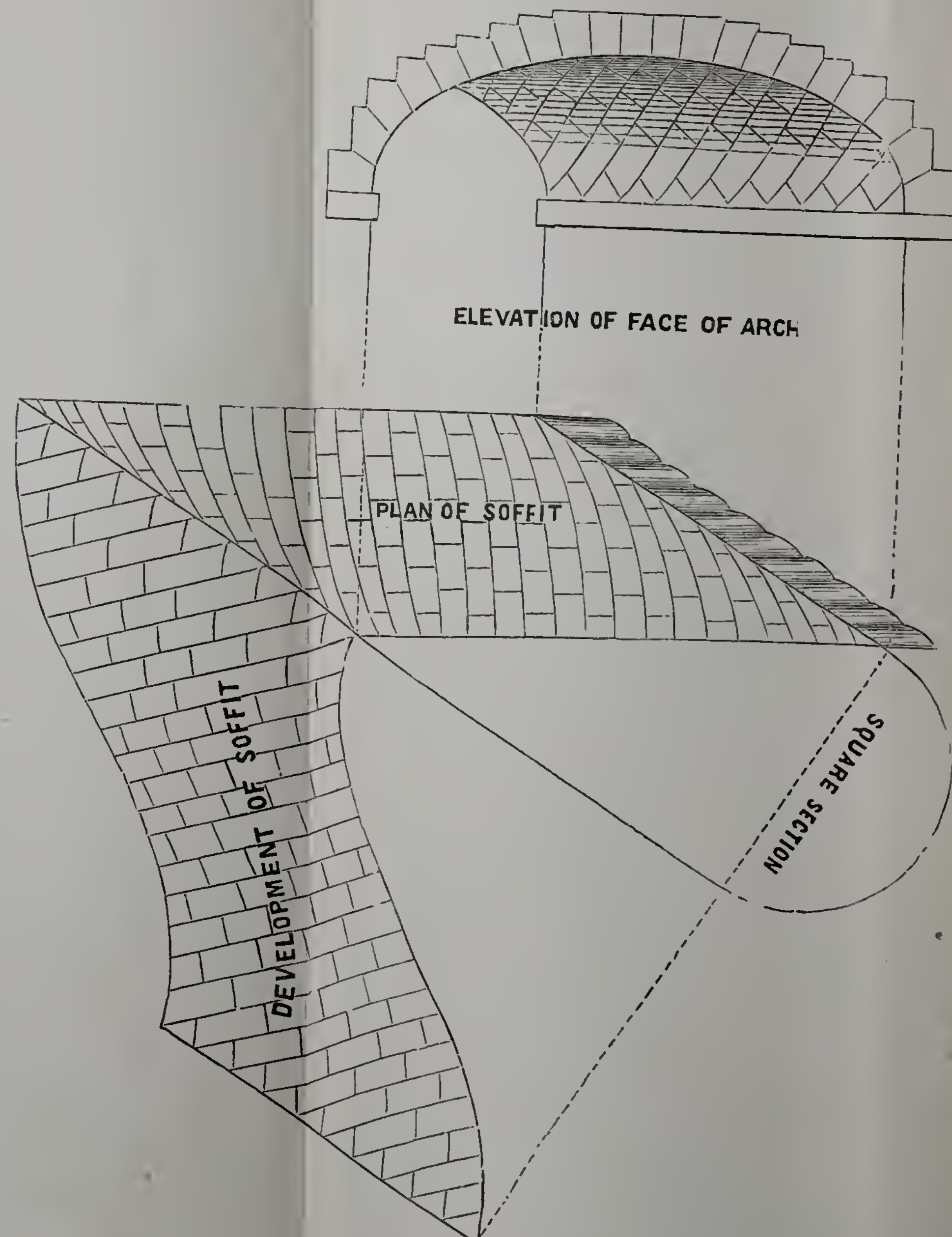

ELEVATION OF FACE OF ARCH
PLAN OF SOFFIT
DEVELOPMENT OF SOFFIT
SQUARE SECTION

FIG. 12.

FIG. 13.

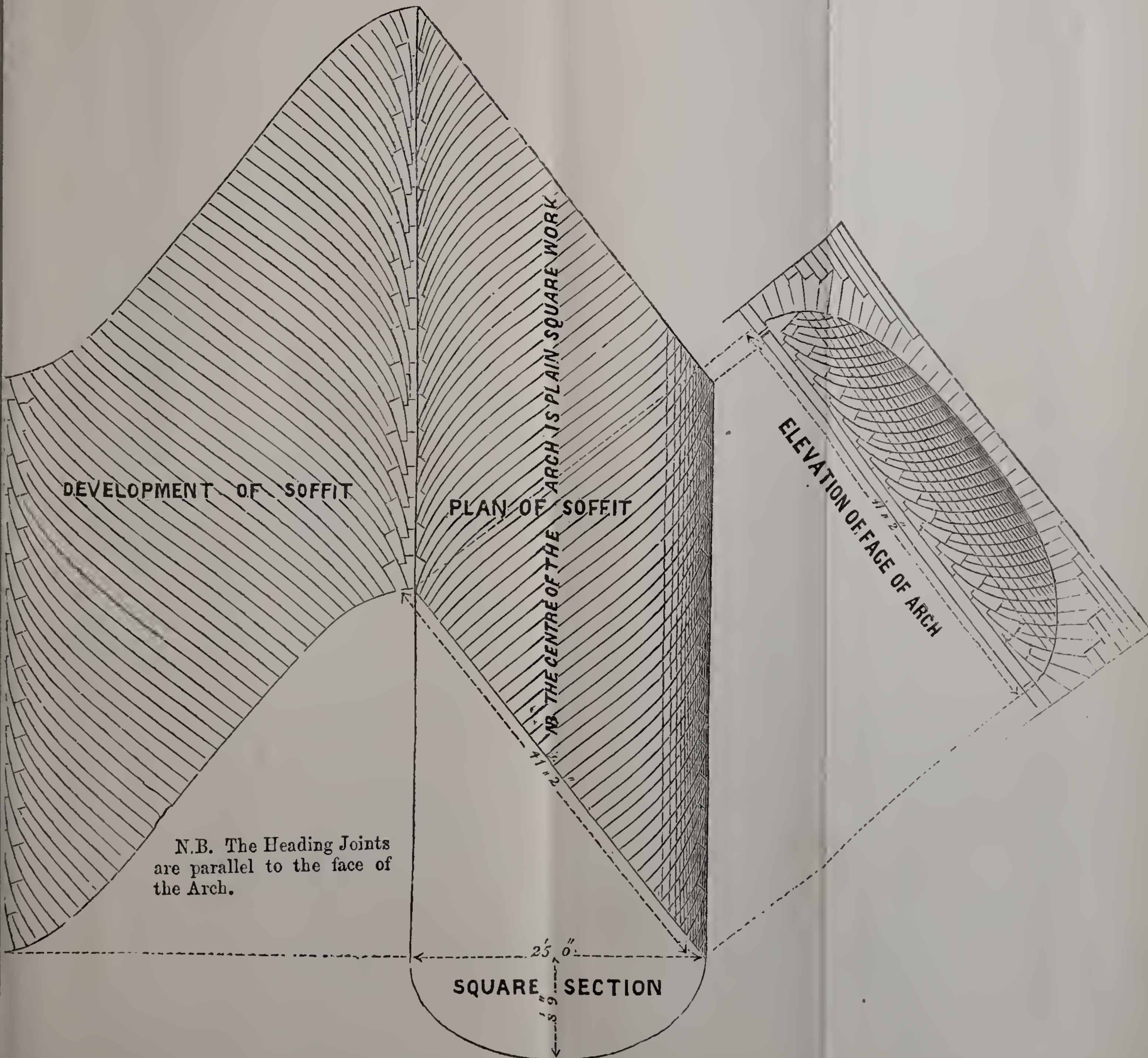

DEVELOPMENT OF SOFFIT
PLAN OF SOFFIT
N.B. THE CENTRE OF THE ARCH IS PLAIN SQUARE WORK
ELEVATION OF FACE OF ARCH
SQUARE SECTION
25′ 0″
6′ 3″
11′ 2″
N.B. The Heading Joints are parallel to the face of the Arch.

FIG. 38.

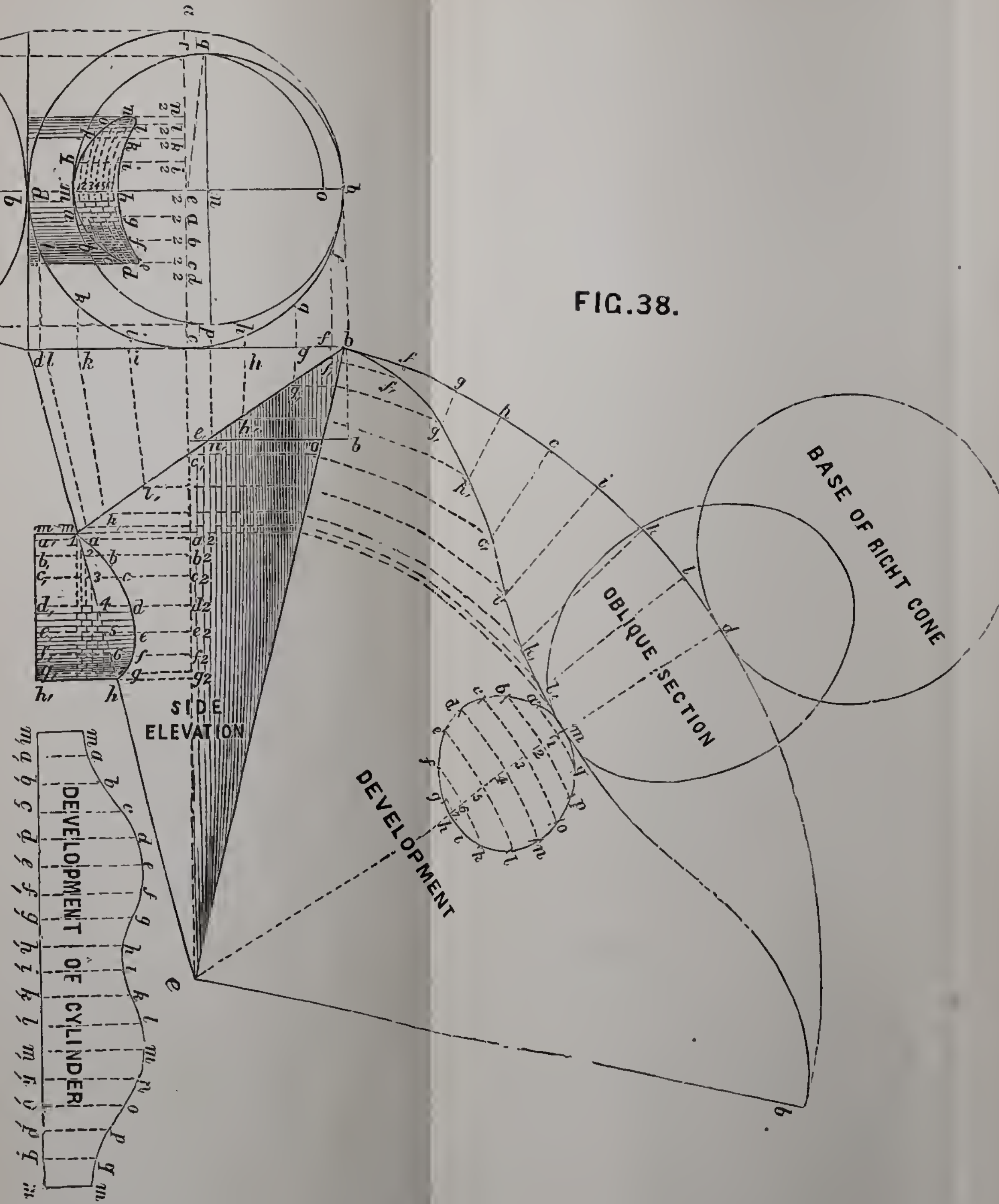

FRONT ELEVATION
SIDE ELEVATION
DEVELOPMENT OF CYLINDER
DEVELOPMENT
OBLIQUE SECTION
BASE OF RIGHT CONE

FIG. 37.

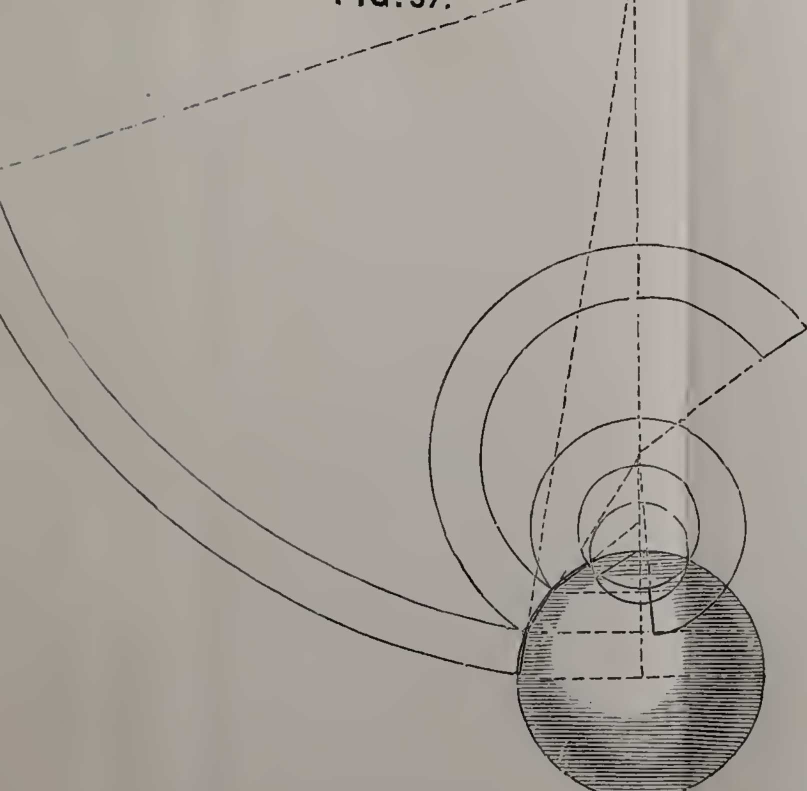
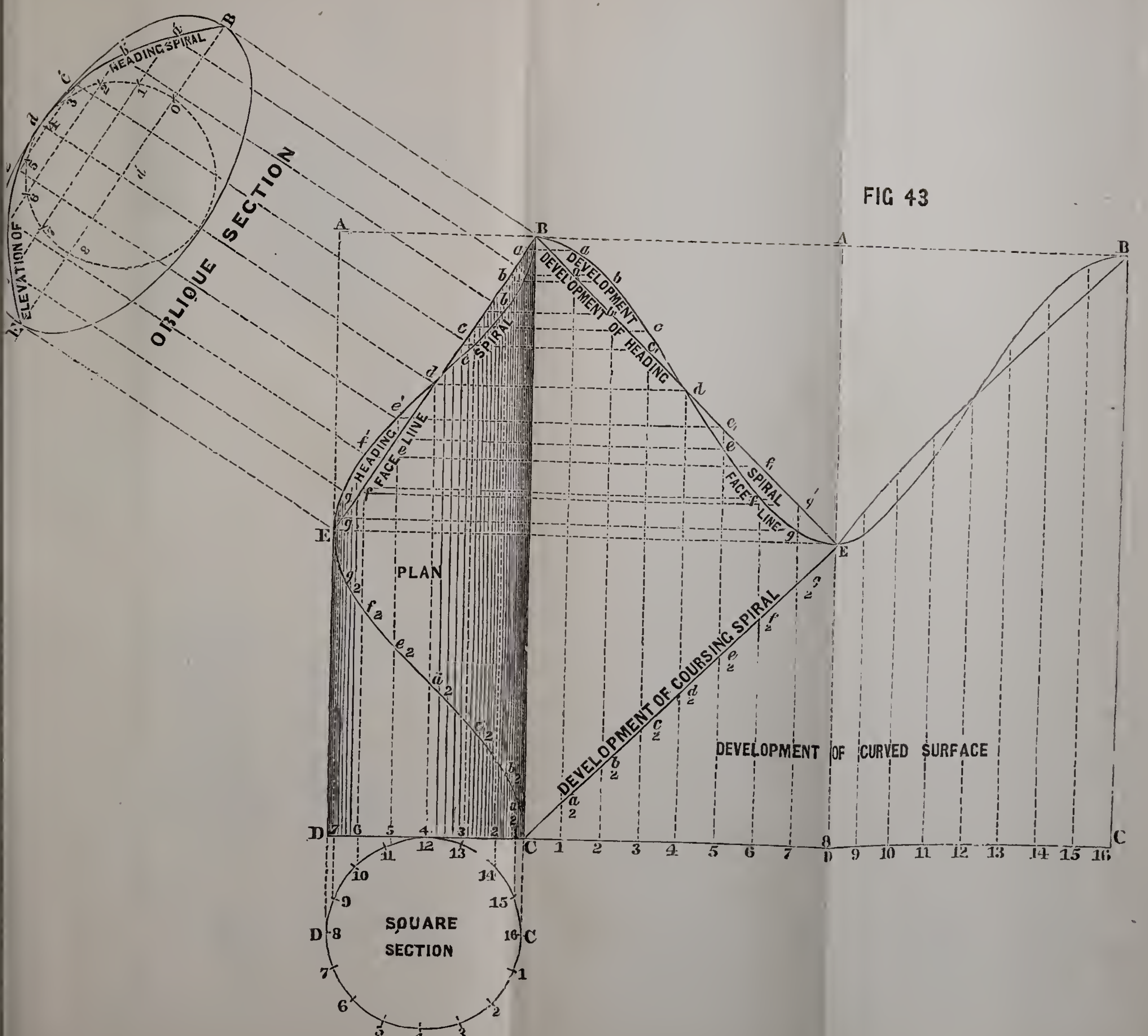


FIG 43


HEADING SPIRAL
ELEVATION OF
OBLIQUE SECTION
DEVELOPMENT
DEVELOPMENT OF HEADING
SPIRAL
HEADING
FACE LINE
SPIRAL
FACE LINE
PLAN
DEVELOPMENT OF COURSING SPIRAL
DEVELOPMENT OF CURVED SURFACE
SQUARE SECTION

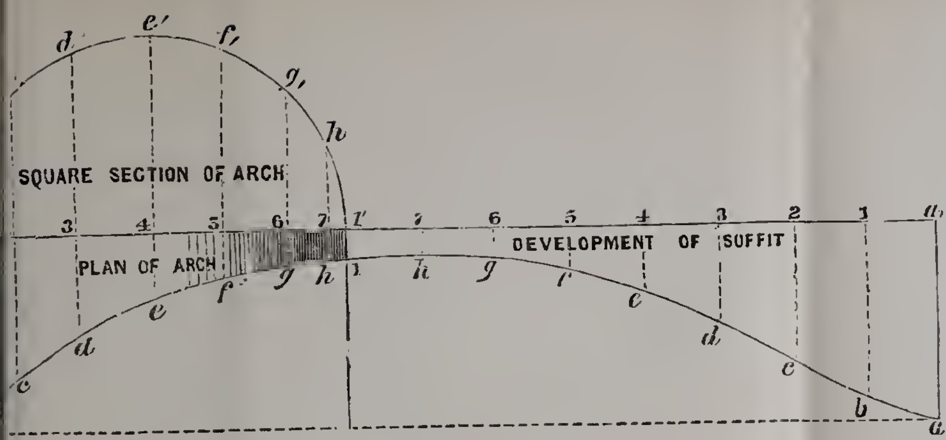


FIG. 44.

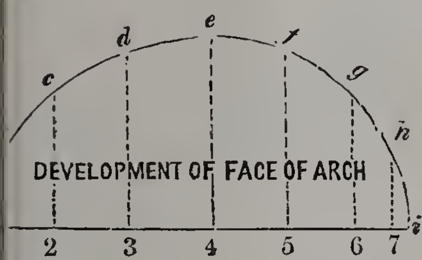
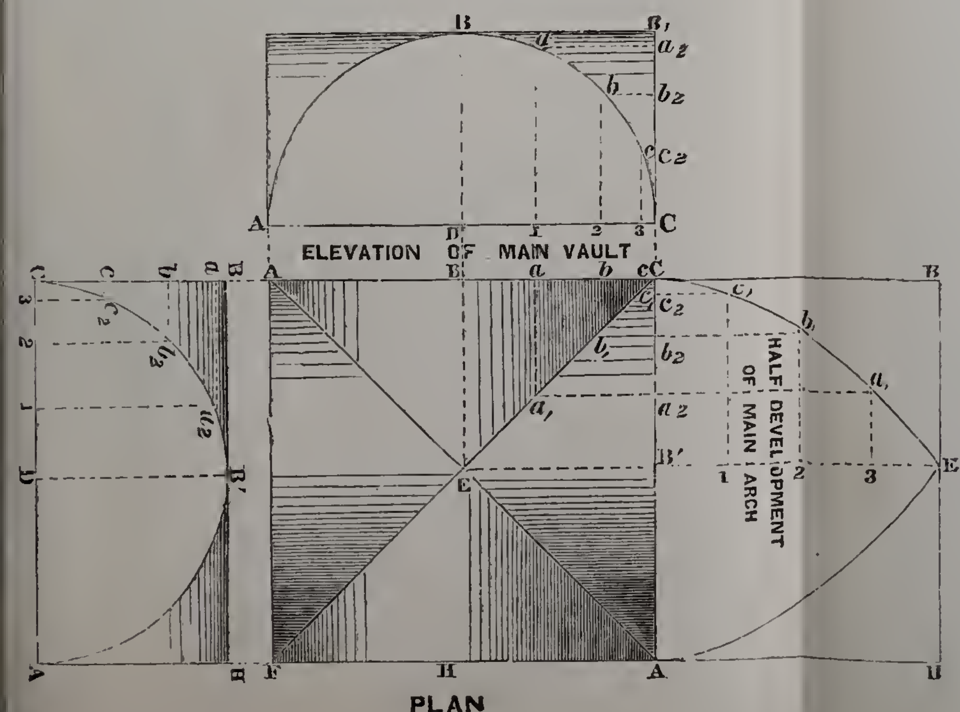


FIG. 45.



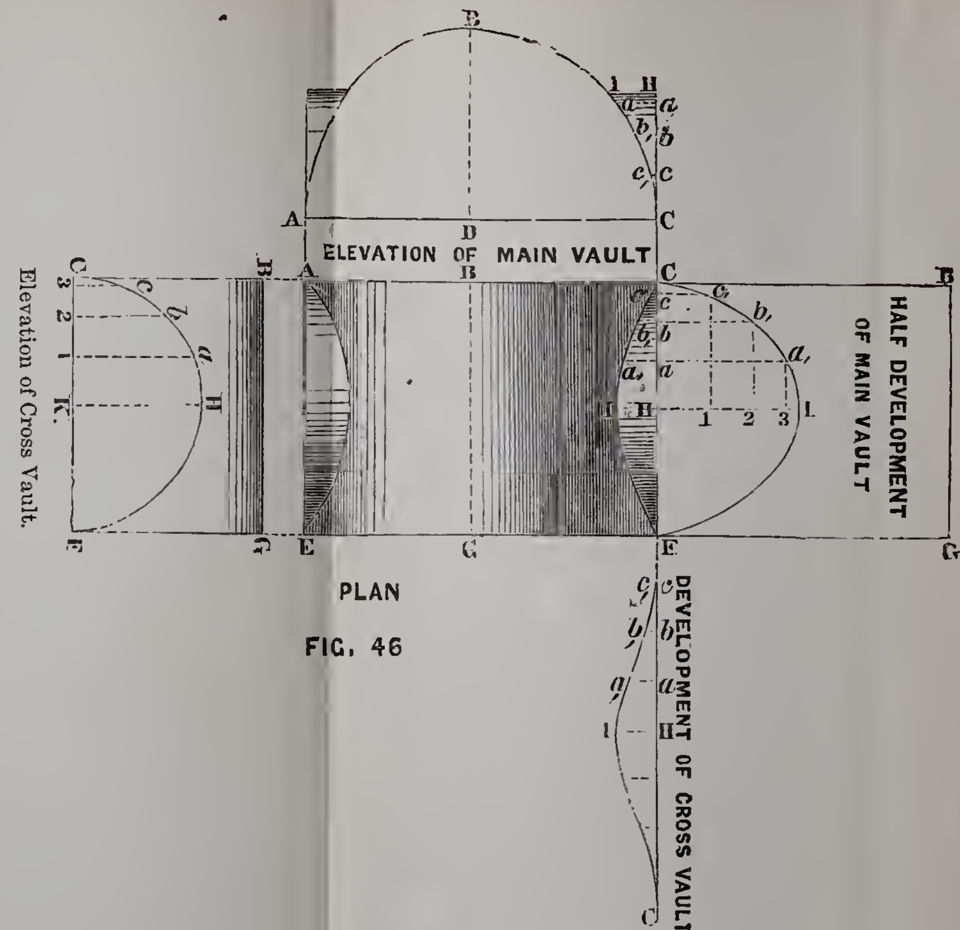


FIG. 46

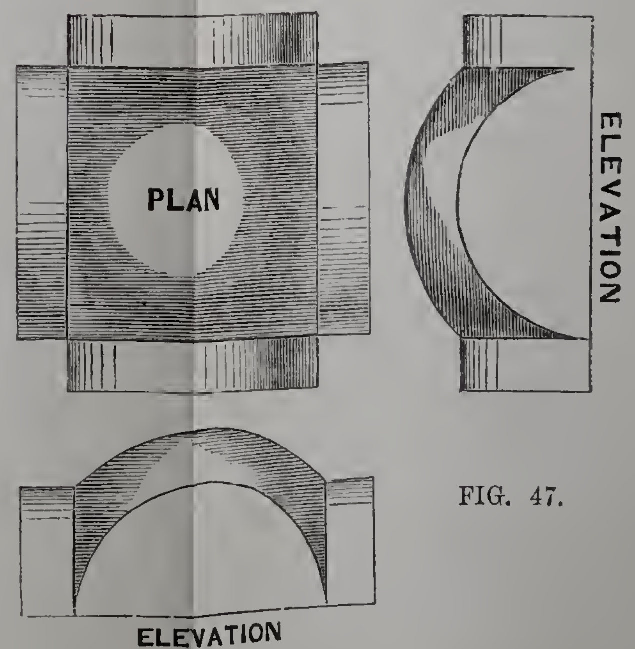


FIG. 47.

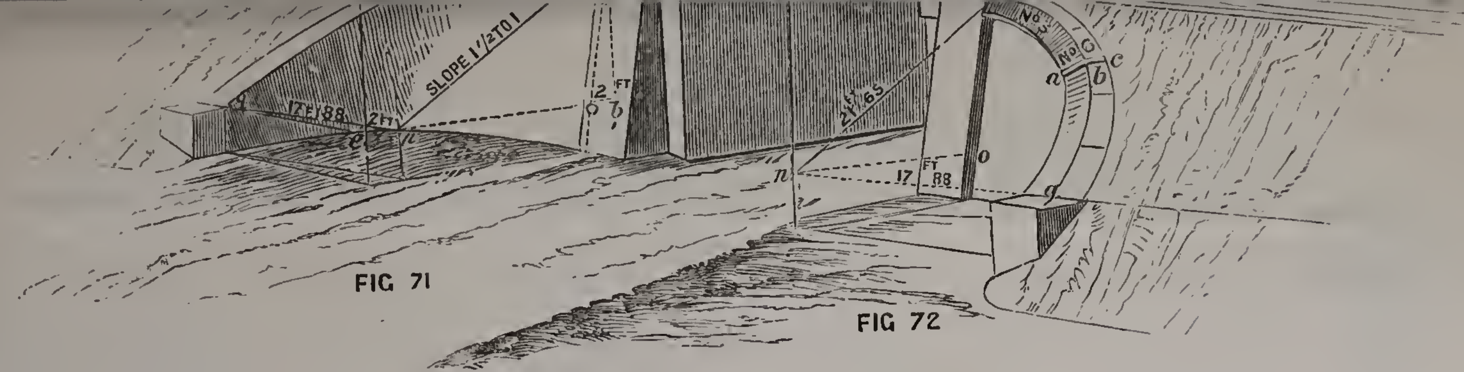


FIG 71

FIG 72

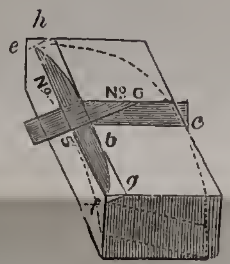
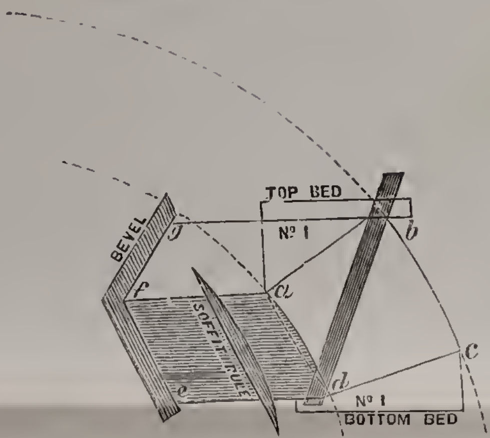


FIG. 73.



FIC 74

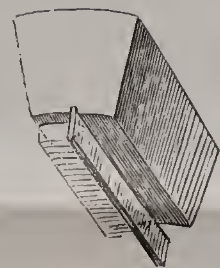


FIG. 75.

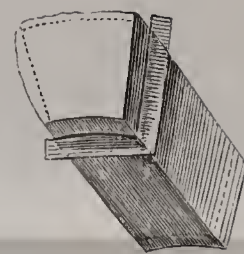
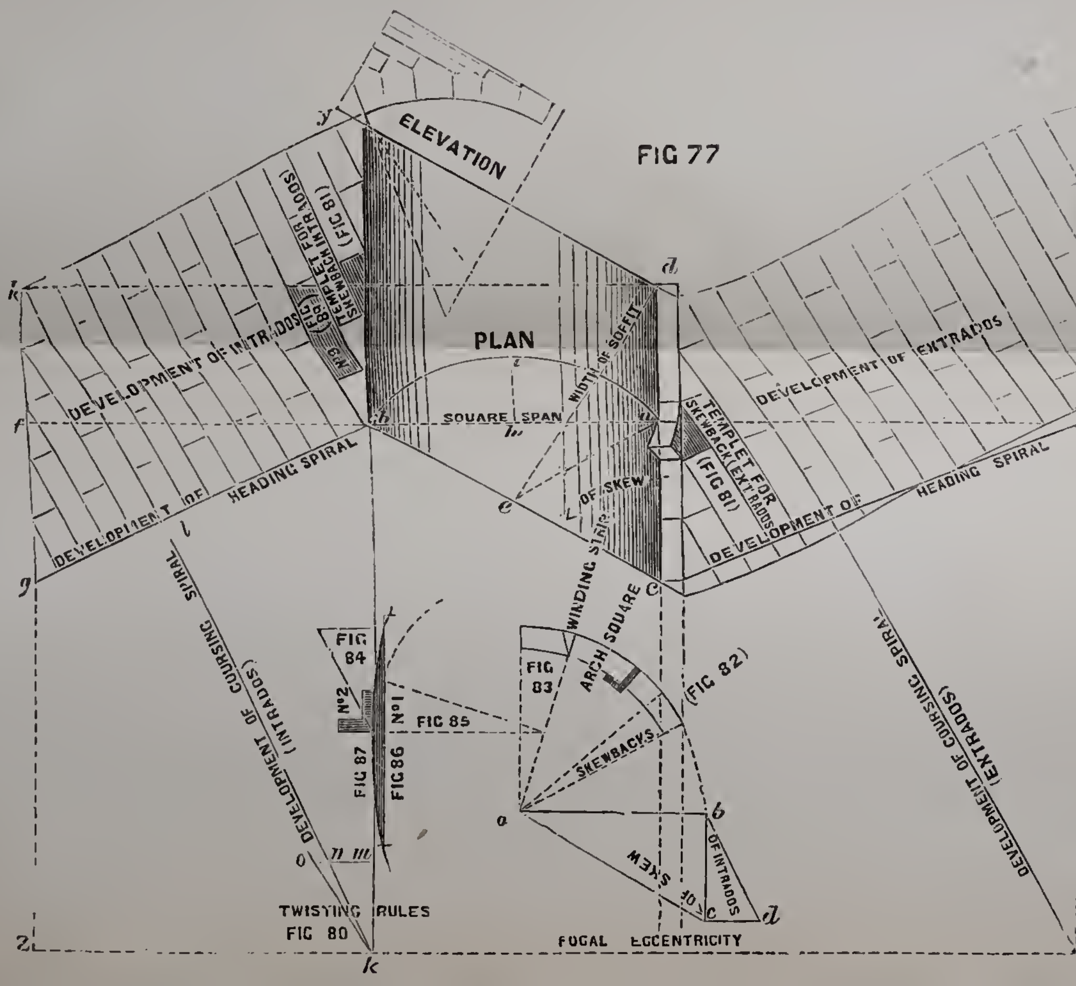


FIG. 76.

FIG 77



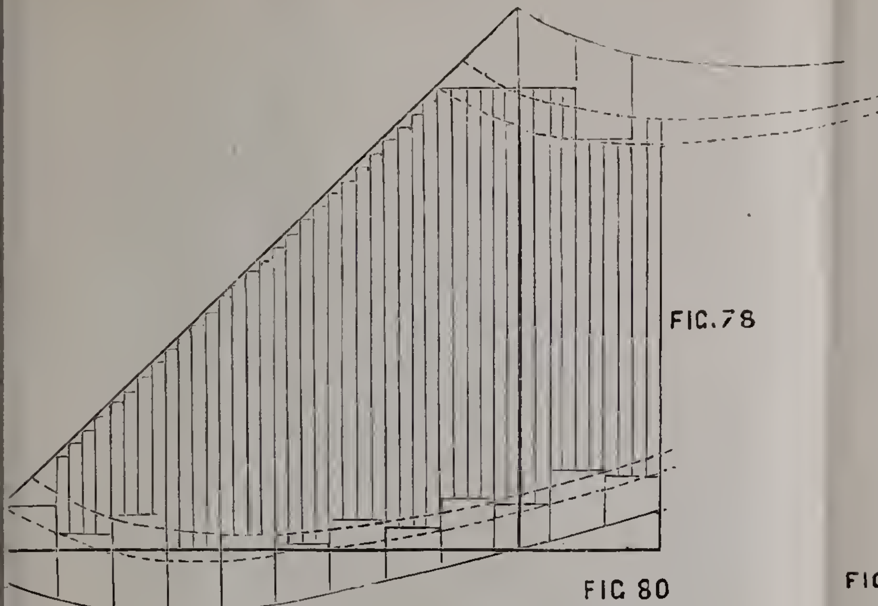


FIG. 78

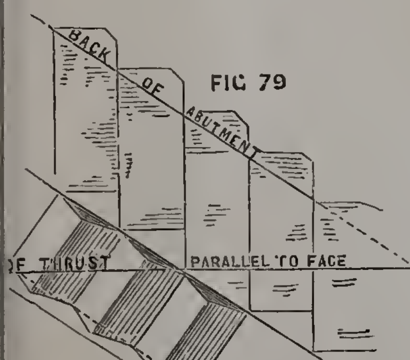


FIG 79

FIG 80

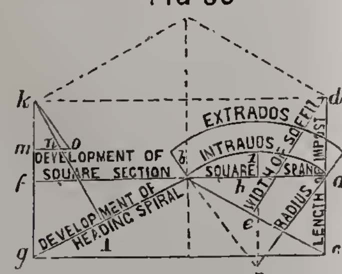


FIG. 81

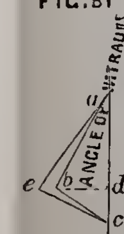


FIG. 82

FIG. 83

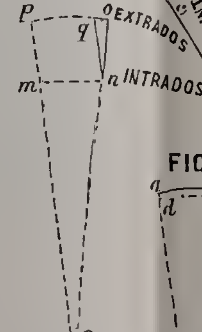


FIG. 84

FIG. 85

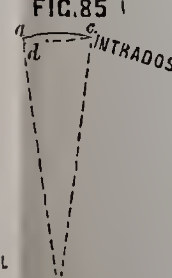
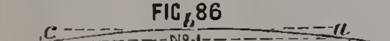


FIG. 86



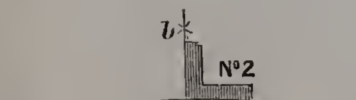


FIG 87

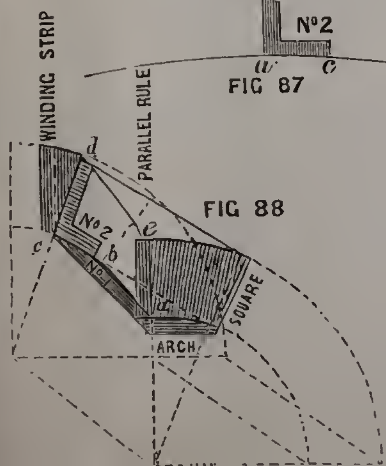


FIG 88

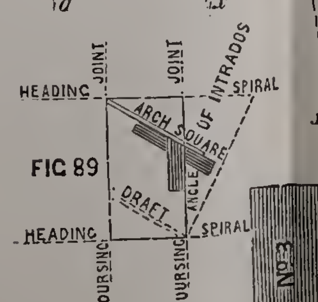


FIG 89

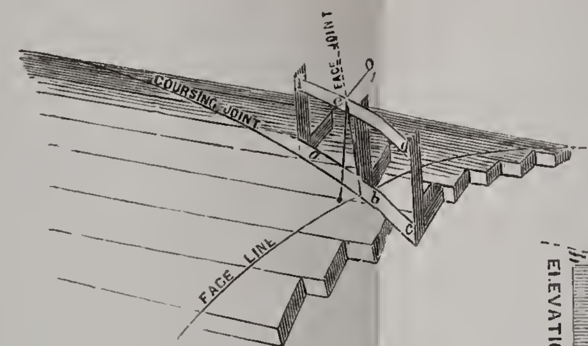


FIG 90

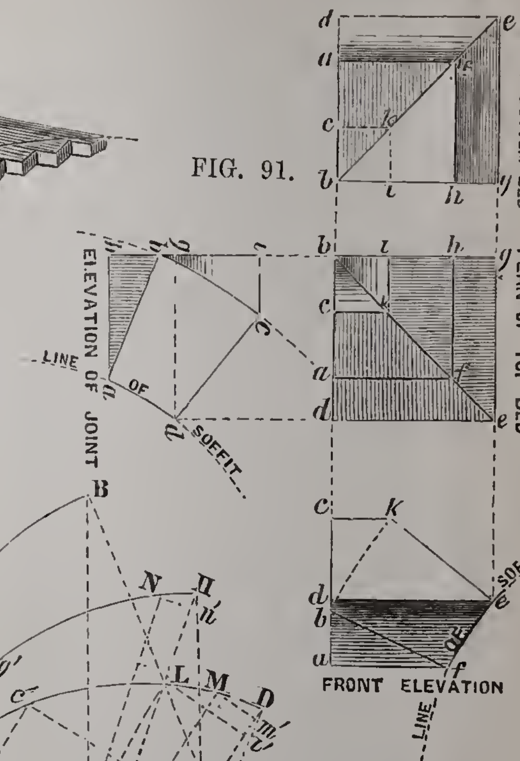


FIG. 91.

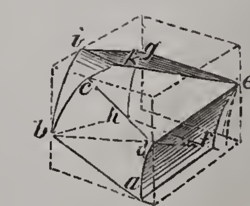


FIG 92

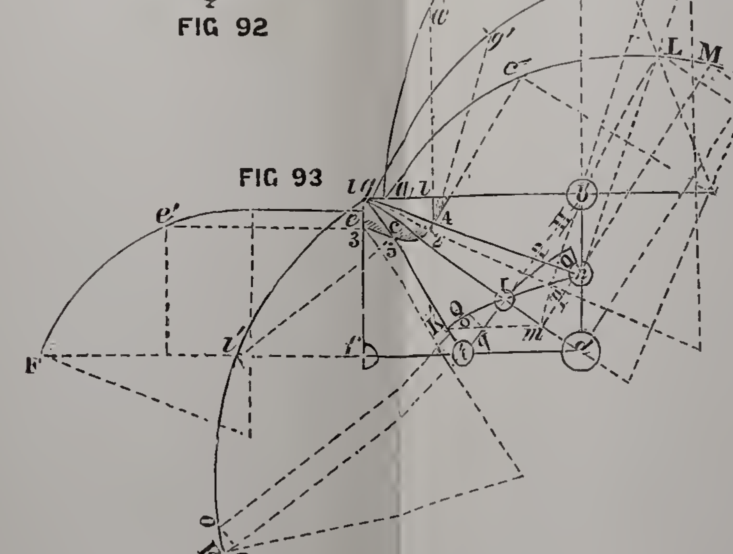


FIG 93

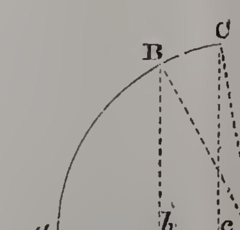


FIG 94

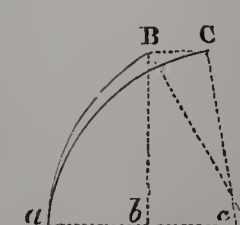


FIG 95

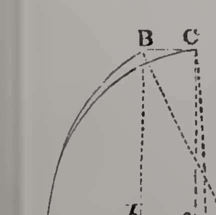


FIG 96

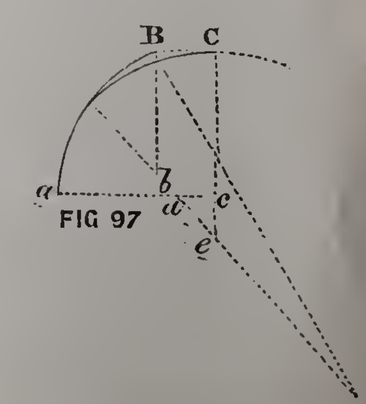


FIG 97

ST MARIE'S ABBEY, BEAULIEU.

Scale 0 3 6 9 12 1 2 3 of Feet.

ST. MARIE'S ABBEY, BEAULIEU.

Foliage on Pulpit in the Refectory.

THE CHURCH OF ST JOHN THE BAPTIST, BISHOPSTONE, WILTSHIRE.

Plate XII.

Chancel Windows

Date Due
